PAPERS

ON

NAVAL ARCHITECTURE,

AND OTHER SUBJECTS CONNECTED WITH

NAVAL SCIENCE.

CONDUCTED BY

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PAPERS

ON

NAVAL ARCHITECTURE,

&c.

Art. I.—*On Mechanical Methods of designing Ships' Bodies.*

The experience derived from examining the past history of philosophy, affords the best directions to the consideration of its future progress. While the principal eras in its different departments present the most interesting objects to those engaged in its investigation, a careful examination of the causes which led to them, and of their attendant circumstances, affords the most useful and legitimate knowledge of the best means of attempting their future improvement.

In tracing the history of the sciences through their different stages, we perceive at one time their rapid strides, at another their scarcely progressive steps, at another their total inaction; —and not unfrequently we are compelled to deplore their retrograde motion towards their previously confined limits. Occasionally we are astonished in the consideration of the lofty flights of genius promising to attain the highest pinnacles of human power and knowledge, but whose continuance was too short to realize our hopes. Again, we see the less brilliant but valuable talents of the many, who, if they made but slow advancement into untried paths of knowledge, were yet usefully employed in making good the ground already hastily possessed. Though ignorance and personal interests have sometimes presented obstacles which produced temporary delays in the advancement of different sciences, yet the mere mutability of these interests necessarily presented frequent openings for advancement, of which combination of events the desire for

knowledge, natural to man, took advantage again to carry forward the subject. The opposition of the enemies to the advancement of knowledge is necessarily weak, by their principal engine of opposition being of a negative character,—the suppression of discussion. If they attack with argument, discussion must ensue; and the certain consequence must be, the increase of knowledge.

In the examination of the causes of the frequent checks to the improvement of the sciences, we may perceive, that they have been frequently more retarded in their progress by the narrow views and selfish egotism of many of their votaries, than by the ignorant or prejudiced opposers to their advancement. One of the most baneful means of impeding the progress of science has ever been, the too hasty endeavour to form theoretical systems, founded either on false or partial views of the subject. It is no doubt highly gratifying, particularly to little minds, to be the founders of systems which they hope may perpetuate their names; but how few have done more than to have raised transitory monuments of their own ignorance or presumption. How often have these aspirants after fame, disregarding the data which philosophy may have afforded at the time, fixed on some favourite hypothesis, and endeavoured to found a system, by exerting themselves in rendering it imposing by the beauty of its theory, and fascinating by the ingenuity of its detail. In many instances, facts were either denied or perverted: an unregretted sacrifice to the idol of their vanity. When false systems have been formed by men of genius, science has suffered still more than from the feebler efforts of ordinary minds, in the check given to its advancement, from the respect naturally paid to their works; which few were able to refute, and fewer dared to attempt.

Most departments of philosophy have, however, ranked amongst their votaries men whose genius has enabled them, by opposing facts to hypotheses, effectually to refute the false systems of their predecessors. Following the road pointed out by Lord Bacon, Newton established his system of astronomy; on the same principles, modern chemists have made their invaluable discoveries: the speculative systems of past ages have gradually ceased to be unduly venerated, and our admira-

tion of beautiful hypotheses has slowly given way to an attachment to the more certain but less imposing process of experimental induction.

Naval Architecture has suffered more than most other sciences by the arbitrary systems of those interested in its improvement. Many, who after a little examination of the subject, have been overwhelmed with its difficulty and extent, have frequently directed their attention to the unphilosophical procedure, of forming systems of design on abstract mechanical principles. Disregarding the fundamental principles of all floating bodies, and too hastily giving up as hopeless, the attainment of a theory combining experiment with established scientific principles, they have contented themselves with ingeniously inventing mechanical methods of forming the designs of ships' bodies, which they did not even pretend to prove had any connexion with the properties of the machine, necessary to ensure the qualities conducive to its intended use. For instance,—some invented methods of forming ships' bodies of arcs of circles; others of arcs of ellipses, parabolas, or of whatever curve they might arbitrarily assume. Taking any one of these curves as the principle of their design, they investigated, with mathematical accuracy, the means of completing the form of the ship's body in correct accordance with their assumption. They did not attempt to show that these curves possessed any property which would render a ship a faster sailer, a more weatherly, or a safer ship, than any other curves which might have been adopted in the construction of the ship's body.

Some of these methods have not, however, even the apparent advantage of the ingenious application of mathematical knowledge to the formation of the system; for the lines representing the different sections are sometimes formed by arcs of circles, which the inventors knew no means of connecting so as to form fair lines, except by reconciling sweeps or arbitrary curves, which the eye of the constructor was left at liberty to determine. This, however, is no additional fault in this mechanical mode of designing ships' bodies; the eye of the constructor may in many cases be preferable to the more regular methods of completing the form; indeed, the determination of the form

of a ship's body, altogether by the experienced eye of the practical builder, who has formed a kind of theory of his own, by observing the coincidence of different forms with certain qualities, which the ships he has built have been found to possess, is far more reasonable—more philosophical, than the dependance on regular curves, of the effect of which, in the formation of the design, the constructor is wholly ignorant.

In denominating any of the mechanical methods of forming ships' bodies a design, it is perhaps claiming too high a character for this unphilosophical mode of construction. By the scientific design of a machine, is generally understood the arrangement of its parts according to those principles on which its required properties depend. It is not allowable to speculate on the chance of any arbitrary assumption being conducive to its excellency, without knowing that it contains some principle, whose action tends to produce the desired effect.

The advocates for the use of these mechanical methods of construction say, that while those who refuse to use them, are left wholly to their judgment in the design of the forms of ships, they themselves have a *system*, which they apply to ship-building, that renders the exertion of the judgment less necessary. This argument assumes an abstract excellency in the possession of a *system*, as if it were more than a general term, which depends wholly on the epithet connected with it to give it any value. In all departments of knowledge, systems have been abundant enough to teach us not to attach necessarily any excellency to them. Experience has shown, that bad systems have been much more numerous than good ones, in all ages and on all subjects. It certainly becomes absolutely necessary to prove the excellency of the system; the mere existence of a system proving nothing favourable to it.

It is said in favour of these mechanical methods, that they afford an easy method of rendering the ship's body fair, and that a symmetry is preserved by them in the successive sections of the body. This is probably the strongest argument which their advocates can advance in their favour. It is certainly true, that many of them afford a ready and quick method of describing the sections of the fore and after bodies of a ship, in relation to the midship section, so that their contour may

partake of its form throughout the ship's length, gradually diminishing their likeness to the midship section as they approach the extremities forward and abaft, till they end in the stem and sternpost.

Whatever apparent facility these methods may thus afford to the formation of ships' bodies, it must be admitted, that by this arbitrary determination of the form, it prevents the judgment of the constructor being exercised in designing the fore and after parts of the body, according to such knowledge as he may be in possession of, and excludes all hope of improvement.

The adoption of any of these mechanical systems is directly opposed to the advantage, which naval architecture might obtain from the experience of naval officers. Knowledge which they may have obtained by observation at sea, might be rendered highly useful to the improvement of this science, if subjected, in the ordinary way of philosophical inquiry, to the examination of the elements of the design on which the observed qualities of the ship depend.

Many of these mechanical systems are of such easy application, that the form of a ship may be determined on the mould loft floor, even without drawings, in a few hours; and many of them are so simple, that persons possessing little or indeed no knowledge of naval architecture, may be taught them in as short a time. The invention of such systems is so easy, that, were it considered desirable to increase their number, persons with very little mechanical knowledge might invent almost any number of them. Those already published appear, however, more than sufficient, as the time is now past for their use: most practical builders are acquainted with several of them, but few consider them worthy of adoption.

Scientific men despise, even more than practical men, these unscientific systems of construction: they consider all such mechanical systems as trammels on science. When treated merely as methods of "fairing" bodies, they give them all the merit they can claim; and if they reject them in practice, it is because they know them to be altogether useless, and worse than useless, by substituting narrow-minded and arbitrary methods for legitimate scientific means of using such knowledge as the

state of the science affords, by the use of established principles and well-authenticated facts.

These mechanical systems constitute what have been denominated the secrets of naval architecture. Mysteries and secrets in science are now fast approaching their proper state of neglect and contempt. Philosophy has shown their absurdity, and common sense awards their judgment. Duhamel, in his '*Elémens de l'Architecture Navale,*' remarks on the use of these systems, page 315 :—"Ces methodes méchaniques et serviles, quils ont mal-à-propos généralisé, ont produit toutes ces pretendues regles de proportion, toutes ces methodes pour former le maitre couple, pour reduire les autres, pour tracer les gabaris, &c., que chaque constructeur essayoit de conserver a sa famille. Quelle petitesse ! c'est comme si un grand architecte vouloit cacher ou faire mistere des proportions des ordres d' architecture. Il faut autre chose que ces regles mechaniques, il faut raisonner sur ce que l'on fait, et pour raisonner consequemment, il faut de la physique, des mathematiques, il faut scavoir la méchanique des solides et celle des fluides, et tellement combiner son object, qu'on parvienne (en procurant à son vaisseau une bonne qualité) à ne pas lui en occasionner une mauvaise."

The following mechanical methods have been published in different English and French works on naval architecture. Some of them have been extensively practised, but most of them have gradually fallen into disuse. Some of these mechanical methods are for forming the midship section; others for forming, from a given midship section, the successive sections forward and abaft.

M. Bouguer, in his '*Traité du Navire, de la Construction,*' *&c.*, gives four methods which have been used for describing the midship sections of ships. M. Bouguer observes, that the midship sections are generally formed of arcs of circles; but that sometimes, by their inventors not knowing, that for two arcs of circles to touch without cutting each other, their centres must be in the straight line which passes through their point of contact, the midship section formed by these arcs have had sensible angles in their contour. He shows correct means of preventing this error in the mechanical formation of the midship sections.

The first method he gives, is that of Le Pere Fournier:—"After having drawn the straight line AB (Fig. 1), which represents the length of the midship beam, he describes a circle RANB, which has this line for the diameter, and draws, at the middle of this line, a perpendicular CD, equal to the depth intended to be given to the vessel, which extends from the under part of the beam to the upper side of the keel, which in fact is the foundation of all the heights of naval architecture. Through the point D, he draws a line GH parallel to AB, and, making DG and DH each equal to half the flat of the floor, equal, if so determined, to one-fourth of the whole breadth, he draws the little perpendiculars or verticals GE and HF each equal to the rising of the floor. These little perpendiculars will be equal to the twenty-fourth, eighteenth, or twelfth part of GH, &c. He then finds on GE, produced both ways, to K and S, the point M, which he takes for the centre of the arc of a circle NE, which touches the first circle in some point N, and the straight line EF in E. Then from a point S, taken as a centre, he describes the arc EO, which touching the straight line EF, or the arc NE in E, meets exactly the side of the keel in O. He has thus ANEO for the form of half the section, and forms the other side in the same manner."

M. Bouguer observes,—"It is true that this good father finds the centres M and S only by trial, but nothing prevents their being determined in a correct and certain manner. If EK is made equal to the radius CA of the first circle, or equal to half the length of the beam, and having joined the points K and C by the straight line CK, LM be drawn from the middle point L perpendicular to it, the intersection of this perpendicular and EK, will determine the centre M of the arc NE. For, MC being equal to MK, and EK having been made equal to AC or to NC, it is evident that MN will be equal to ME, and consequently the arc of the circle described from the point M as a centre, and which will pass through the point E, will touch the first circle in N. With regard to the other centre, S, it will be quite as easy to determine it: it is only to draw the straight line EO, and, from its middle point, to draw a perpendicular which will meet IG produced downwards in the point S, which will be the centre of the arc EO. I leave the method

by which the same author forms the upper part AQR, since it does not appear that he would have often any inconvenience in the use of it. He describes AQ, by taking the point I as a centre, and gives to QR a radius of the same length."

The second method given by M. Bouguer does not differ very materially from this of Le Pere Fournier. Both these methods were recommended for ships of the line, the form of whose bottoms is between that of frigates chiefly constructed for velocity, and that of ships of burden principally constructed with regard to their lading.

The third method is for determining the midship sections of flat-floored ships: it was invented by M. de Pulmi, of Brest, who is highly eulogized by M. Bouguer, for his successful examination of the geometrical properties of the curves; he recommends it to be introduced into the formation of ships' bodies, without, however, as M. Bouguer observes, "ascertaining their physical or mechanical properties; although they are, as is evident, the only properties which can in reality have anything to do with the subject."

Admitting the ingenuity of M. de Pulmi as a geometrician, his particular attention to such investigations, certainly appears to prove him but a very poor naval architect.

"He forms a rectangle ABIL (Fig. 2), which has for its breadth the length of the beam, and for its height the depth of the hold. He determines at E and F, the extremities of the flat of the floor, GE and HF, which give the rising; he then forms a square (Fig. 3), whose sides are equal to LG or KE, and inscribes in it two quadrants of circles AQE and AXE. He then divides the one arc AXE into a certain number of equal parts, AV, VX, XY, YZ, &c., drawing from the points of division VO, XN, &c., perpendicular to the radius AK; he divides into the same number of equal parts the depth of the vessel (Fig. 2), from the rising of the midship floor, and transferring to level lines drawn through these last points of division O, N, &c., the parts OS, NR, MQ, &c., intercepted in Fig. 3 between the radius AK and the arc of the circle AQE, it only remains to pass a curve ASRQPE through the extremities of all the perpendiculars or ordinates OS, NR, &c., and the contour of half the first section is obtained. It is true that it is neces-

sary to complete ED; but this can be done simply with an arc of a circle, which, touching the first curve at E, joins the side of the keel at D; and it will be necessary to do precisely the same for the other side."

The fourth method given by M. Bouguer, is recommended for sharp ships.—"Having formed, as before, the rectangle ABIL (Fig. 4), circumscribing the part of the section below the midship beam AB, the rising GE or HF of the midship floor is made equal to a fifth or sixth part of the flat of the floor GH. The points E and F being determined, two portions of parabolas AE and BF are drawn, A being the vertex and AC the axis of the one, and B the vertex and BC the axis of the other; the flat of the floor is formed by two arcs of circles, the convexity of the upper arc being below, and of the lower arc above. Having drawn, from the point E, EK and EM perpendicularly respectively to AL and AC, he describes, from a centre in AC produced indefinitely towards N, the semicircle MKN passing through the points K and M; then AN will be the parameter of the parabola, which will serve to find as many points in the curve as may be desired. If it be required to find a point in the vertical line PQ, through which the curve will pass, it will be found by describing the semicircle NOP, and drawing from the point O, where the semicircle cuts AL, the horizontal line OQ, the point Q the intersection of this line with PQ will be a point in the parabola. In the same manner, any number of points may be found. In order that the first arc of the circle of which the flat of the floor is formed may not make an angle with the parabola, it is necessary that its centre may be situated in some point S of the perpendicular to the parabola ER. To draw this perpendicular, it is only necessary, as all geometricians know, to make the sub-normal equal to half the parameter AN."

These methods are sufficient to show the nature of the mechanical systems of drawing the midship sections of ships. If their authors had shown us, that such methods would give the ships any particular quality,—even if they had shown a probability of excellency, which might have ever so little dependance on the prescribed process, we might have respected their exertions in the cause of science. By recommending one

method for ships with flat floors, another for ships with very rising floors, and another for ships with floors of an intermediate degree of fulness, it might lead to the supposition that there was, in each of these methods, a peculiar adaptation for these respective forms; but even this is not true in any great degree: for, with very trifling modifications, some of these methods may be applied with equal success to the formation of midship sections of the opposite character to that assigned to them. It may be admitted, that the author of any of these plans, whose methods will correctly join the different arcs, is entitled to a little higher consideration, as a geometrician, than another, whose ignorance of geometry obliges him to join the arcs by reconciling sweeps; yet it gives him no higher claim to consideration as a naval architect.

When a midship section is determined either by any of the mechanical methods, or by any more scientific method of design, with the length of the ship, and the rake of the stem and sternpost, it becomes necessary to form the fore and after parts of the body.

We will proceed to give some of the mechanical systems of forming the sections of the fore and after bodies of ships. This operation affords a greater scope for ingenuity than the formation of the midship sections of ships, and consequently the methods proposed have been much more numerous.

The principal lines used in the construction of ships' bodies, are the main breadth lines, the top breadth lines, and the rising and breadth lines of the floors. These lines are shown in two planes, a longitudinal vertical plane, and a longitudinal horizontal plane. The rising of the main breadth line shows the projection on the longitudinal vertical plane of the heights above the upper side of the keel of the greatest breadths of the different vertical sections fore and aft; and the horizontal main breadth line shows the corresponding distances from the middle line of the ship at the respective sections. The rising of the top breadth line, and the horizontal top breadth line, show in the same manner the heights from the upper side of the keel, and the horizontal distances from the middle line of the ship, of the different vertical sections at the top breadths of the timbers. At these heights and at these distances from the middle line,

arcs of circles are generally described, which give the form of parts of the vertical sections, or of the frames of the ship. The rising line of the floors gives, in the same manner, the heights above the upper side of the keel; and the horizontal breadth line of the floors gives the distances from the middle line, at which the floor sweeps commence.

One of the oldest methods of forming a ship's body, is that which is called "whole-moulding." It was formerly much in use; but as the knowledge of the science has improved, it has gradually sunk into deserved neglect. It is in the present day scarcely used, except for ships' long boats, which in some yards are still built by it. It will, no doubt, shortly fall into complete disuse, and be only known as a matter of curiosity in the history of construction.

Whole-moulding is a method of constructing the square body,—that is, all the body except the fore and after extremities of a vessel, where the planes of the frames are placed obliquely to the middle line, by means of two moulds; the upper one giving the form of the timbers above the rising line, and the lower one (called the "floor hollow") giving the form of the timbers from the rising line to the keel.

The midship section is first formed, usually by arcs of circles; and at the height of the rising line in this section, a horizontal tangent is drawn to this curve. In order that the tangent of this curve may be horizontal, the centre of the arc forming the lower part of this curve, must be in a vertical line passing through the point from which the tangent is drawn. The lower part is formed by a sweep which reconciles with the upper curve. Usually this sweep does not correctly touch the upper curve, although the inaccuracy is not very important in this method of construction. In forming the body plan, the heights of the main breadth and rising line, at the different frames, are set off, and the different sections drawn by the two moulds. On the horizontal part of the upper mould ABC (Fig. 5), are marked the half main breadths of the different sections, as shown at C; and on the upper part of the mould, their heights, as at A; the lower mould, DEF, is also marked where it meets the side of the keel at the different sections.

In moulding any timber, a square, called the rising square,

with the heights of the different risings of the timbers marked on it, is used, by which the moulds are set according to the particular timber, the form of which it is intended to obtain. On this square are also frequently marked the heights of the cutting down, by which the form of the inside of the timber is obtained at the same time. The operation of moulding a timber may be best seen by reference to Fig. 5, where the moulds and rising square are set for moulding the lower futtock, No. 8.

In Duhamel's 'Elemens de l'Architecture Navale,' there is a French method nearly resembling this method of whole-moulding.

In Mungo Murray's Treatise on Ship-building, a method is given for forming a ship's body by the use of the sector. This instrument is formed of two scales, connected by a hinge, which open and shut like a common rule. Seven lines are drawn on each leg of the sector from its centre, divided at numerous points, indicating lengths which refer to different elements of the body. The marks on the corresponding lines on the two legs of the sector refer to the same distances. The lines on one side of the sector are divided for the fore body, and the other for the after body.

The manner of using these lines is thus described:—"The general dimensions being determined, and a scale adapted to the draught, take the half breadth with a pair of compasses, and, placing one foot in the proper point for the half breadth of the midship section, which is shown on one of the lines, open the sector till the other foot reaches to the same point in the corresponding line on the other leg."

The sector being thus set, the different distances are taken by the compasses from the corresponding points marked on the corresponding lines, and set off in the different plans.

It is immediately evident, that, by the use of the sector as described, all ships constructed by it would be similar to that, according to which the distances were marked on these lines. If it is required to form a fuller or sharper body than that by which the lines of the sector were divided, the midship section, with the foremost and aftermost sections, must be determined agreeably to the will of the constructor, and the intermediate

sections will be determined on the diagonals by setting the sector separately for each diagonal, and by then taking the distances from the lines, as before, for the formation of the different plans in the drawing.

The next method of constructing ships' bodies which we shall give, may be found in the *Traité du Navire*, by Bouguer: the diagonals in this method are formed of arcs of ellipses. The midship section is formed at will, and the extreme sections forward and abaft are formed in an arbitrary relation to the midship section. To form the after body by this method, let ABC (Fig. 6) represent the midship section, and FED the after section, and BE the projection of one of the diagonals. Describe the arc of a circle BA (Fig. 7), whose radius is three times the line BE (Fig. 6), and whose versed sine BC is equal to BE. Divide the sine AC into any number of equal parts, according to the number of intermediate timbers it is intended to draw. From these points of division draw the lines DI, EK, &c., perpendicular to AC, and, from the points where these lines intersect the arc of the circle, draw I 5, K 4, &c., parallel to AC. Transfer the line BC, so divided at 1, 2, &c., to BE in Fig. 6, which will give points in which the intermediate sections will cut the diagonal BE. The other diagonals are divided similarly, by taking any point O in AC produced, and joining OB, O 1, &c., and placing the projection of any diagonal as PQ parallel to BC, and with its extreme points in OB and OC. Some constructors prefer dividing each diagonal separately, by describing arcs of circles BA, with different radii: others, instead of dividing the sine AC into equal parts, divide the arc AB into equal parts, and then proceed as before.

The fore body is formed by nearly the same means, but is always made fuller than the after body. Let A*bc* (Fig. 6) represent the midship section, and A*ed* the extreme section forward; produce the projection of the diagonal *be*, to meet the middle line of the body plan in *f*. Describe the quadrant of a circle BA (Fig. 8), with a radius equal to *fb* (Fig. 6), and draw the sine DC equal to *fe* and parallel to FB. From a point E in FA produced, describe an arc of a circle, with a radius equal to once and a half or twice FB, according as it is intended to make the fore body fuller or sharper, meeting CD

produced in G. Divide the arc FG into as many equal parts as it is required to find spots, on the diagonal *b e*, for the intermediate sections; and from the points of division, H, I, &c., draw HM, IN, &c., parallel to BF; and draw P 1, O 2, &c., parallel to FA. Then transfer BF, so divided at 1, 2, &c., to *bf* in the body plan, which will give points in which the intermediate sections will cut the diagonal *bf*. Instead of dividing the arc FG into equal parts, some constructors divide the sine DG into equal parts, and, by drawing lines parallel to FD from these points of division, determine the points of division of the arc FG, and then proceed as before. Instead of making similar figures for other diagonals, they are frequently divided proportionally to *fb*.

M. Bouguer then proceeds to show the method of completing the diagonals before and abaft the extreme sections.

One of the easiest methods of constructing ships' bodies is by means of an equilateral triangle, which is described by Du Hamel, in his '*Elemens de l'Architecture Navale.*' To construct the triangle for the after body, draw any line AB (Fig. 9), and divide it at the points 1, 2, 3, &c., so that the distance from 1 to 2 may be three times the distance A 1 taken at pleasure, the distance from 2 to 3 five times A 1, and so on; the number of points of division corresponding to the number of intermediate sections between the midship section and the sternpost, together with the after section at the sternpost. Suppose the number of intermediate sections to be seven: let the distance from 7 to B be at least equal to the distance between the vertical sections on the plan of elevation. Describe on AB the equilateral triangle ABC; and join C 1, C 2, C 3, &c. The use of this triangle is to divide the projection of the diagonals in the body plan, proportionally to the divisions of the base of the triangle AB.

In the plan of [1]elevation, or sheer plan, take the distance between any two of the vertical sections, and place the line representing this distance, DE, parallel to AB, and so that its extremities may be in the lines C 7 and C B. Produce D E to

[1] This figure is not shown here, as it is considered unnecessary to the description of this method.

F, and take the horizontal distance from the intersection of the projection of the diagonal with the vertical section, 7, to where the projection of the diagonal meets the projection of the after fashion piece; and place this distance DG on DH, keeping one of its extremities in D: then join CG, and produce it to meet the base AB produced in H. Take the projection of this diagonal in the body plan, IK (Fig. 10), from the midship section LIM to the fashion piece NKO, and place it in the triangle parallel to the base AB, and with its extremities i and k in CA and CH; the lines C 1, C 2, C 3, &c., will divide the line ik proportionally to the divisions of the base of the triangle AB. Transfer this line, so divided, to its place in the body plan: the points 1, 2, 3, &c., will give spots through which the intermediate vertical sections will pass.

Some who have used this method of forming ships' bodies, placed the projections of all the diagonals parallel to the base of the triangle; others placed them at different angles with the base. Du Hamel recommends their being placed as follows: the projection of the lower diagonal, representing the floor ribband, parallel to the base; the projection of the second diagonal at an angle of 62°30′, with the part of the side of the triangle above the projection of the diagonal; the third at an angle of 68°; the fourth at an angle of 86°; the fifth at an angle of 65°; and the projection of the sixth, or top breadth ribband, at an angle of 60°.

To construct the fore body, a nearly similar process is adopted, but the base of the triangle is differently divided,—generally in a geometrical progression, whose common multiplier is 2. The divisions of the bases of the triangles, however, are altogether arbitrary, as well as the angles of inclination, at which the projections of the diagonals are placed, for both the fore and after bodies.

These are some of the most esteemed mechanical methods of constructing the midship sections of ships, and the fore and after bodies in relation to them. The inspection of them clearly shows, that these methods are altogether arbitrary, and that there is no attempt to describe any form which is proved to possess any property conducive to the good qualities of a ship. In forming a midship section by arcs of circles, it has

been said, that this figure has been chosen because a circle contains the greatest area under the least periphery. Supposing even that this principle were introduced into the form of a midship section, which is however frequently destroyed by the use of *several* arcs of circles, yet it by no means establishes the propriety of using the arcs of circles in the construction of the form of a midship section; because it would first be necessary to show, that it would be a good property for a midship section to contain the greatest area under the least periphery. In fact, the principles of ship-building require a contrary practice: a flatness is requisite in some parts of this section instead of rotundity, to give lateral resistance, great stability under a given area, and fine water-lines. The use of the ellipse or parabola is equally arbitrary.

Of the four methods of constructing the bodies of ships which have been described, little appears capable of being said in their favour;—and indeed little appears necessary to be said against them, as they evidently appear to be totally devoid of any claims to excellence, by the total absence of all attempts in them to apply such principles as are known by experience to affect the qualities of ships. Whole-moulding is an unskilful method of making the consecutive sections partake of the form of those preceding, by preserving the curve of the midship section throughout the body, only placing the greatest curvature at different heights. It requires the breadth of the ship at the surface of the water to decrease forward and abaft, from the midship section, as much as the breadth is diminished below; so that the mere operation of forming the lower part of the body so as to make the lower water-lines fine, necessarily prevents the fulness at the surface of the water being retained as far forward and aft as a due attention to the stability of the ship may require. Its inapplicability at the extremities of the ship, is also an error in its mechanical adaptation to practice. The second method described, constructing ships' bodies by the lines of the sector, is inapplicable to general use, because all ships constructed by it would be similar to that according to which the lines of the sector were divided, without very considerable difficulty in its alteration; while the principles of ship-building require great difference between the relative

proportions of large and small ships: besides the necessity of adapting the form of the ship to the particular service for which it was designed. At least, this method would require as many sectors constructed as there are classes of ships differing in size and service. The third method described for dividing the diagonals by the construction of the Figures 5, 6, and 7, is such a complication of arbitrary operations, and requires also the construction of the foremost and aftermost sections, that it has not even the claim of simplicity and easy application to practice. The last method described, dividing the diagonals by means of triangles, is certainly capable of being readily understood and easily applied; and if any reason could be assigned why such a division of the diagonals would produce any good qualities in the ships constructed by this method, its facility of application would render it useful. But this is the fundamental error of all mechanical methods of construction,—that they not only prevent every legitimate attempt at improvement, but they prevent the use of such knowledge as has already been obtained in the science, by the application of well-established principles and valuable experience.

In some of the mechanical methods of construction, two sections, called balance sections, were introduced, at the middle points between the midship section and the stem and sternpost. They were denominated balance sections, from their being supposed to balance the capacity of the fore and after bodies, by having the same breadths at certain heights; the reason given by Duhamel for their use, is, that by their means the centre of gravity of the part of the displacement contained between them might be near the midship section: an incorrect method of obtaining not merely an unnecessary, but an improper adjustment of a ship's body.

The parabolic system of construction, described in Vol. I., Art. XVIII., invented by Chapman, must be classed among the mechanical modes of forming ships' bodies, of which it appears to be by far the most ingenious. Happily, however, for the fame of this great man, his character as a naval architect does not rest on this invention: his original and extensive views of the science of naval architecture, his persevering devotion to its interests, and his great experience, rank

him among the greatest naval architects, if not the first, that ever lived. It is remarkable, that there is scarcely any principle known in this science, which has not in some way been alluded to in his works. Fully sensible of the importance of mathematics to naval architecture, he constantly applied them to its investigation; but, from his limited acquaintance with them, the subject did not always obtain that advantage from his labours, which his other attainments promised.

His desire to combine his extensive experimental knowledge with mathematical investigations, and to form a system of general applicability to the design of ships, influenced him in his formation of the parabolic system of construction.

His system is founded on an analogy, which he says obtains very generally in the forms of ships,—that their different lines conform very nearly to the curves of parabolas. On this he proceeds immediately to form his method of construction, which is to give to the principal sections of a ship (the midship section, load-water section, &c.) the form of a parabola, depending on the fulness of the ship for the order of the curve. Now if it had been ascertained, by an extensive experience, that the lines of *good* ships were nearly coincident with the form of a parabola, and that the lines of *bad* ships either deviated from this curve in proportion to their defects, or were generally of other forms, it would at least be a valuable fact; but, as bad as well as good ships equally partake of the form of this very general curve, it certainly adds nothing useful to our acquaintance with the science of naval architecture. As a mere system, it shackles the constructor; though, from the extensive variety the different orders of this curve admit, it confines his views less than many other of the mechanical systems. It leaves the principal elements of design free for the constructor's consideration; but it determines many of the apparently minor elements of the design, which, in fact, greatly affect the ship's general excellency. In common with all mechanical systems of construction, its investigations relate merely to the geometrical properties of the curve, while its physical properties are altogether neglected. Denying its pretensions to an improvement in the construction of ships, and condemning it as narrowing the investigation of the science of naval architecture, it may

however be considered, in another point of view, as merely affording a method of estimating the relative fulness of a ship technically. By this method of estimating the form or a ship's body, scientific constructors may form a tolerably correct estimate of the relative fulness of the principal sections of a ship by the exponents of the different curves; so that it might afford a kind of technical language, in which naval architects might speak on the forms of ships. It might give to a person unacquainted with the system, a false notion of the knowledge of those who spoke of midship sections, load-water sections, &c., according to its peculiarities, and might give an appearance of mystery to naval architecture, which is directly opposed to this, in common with all departments of science.

It is well for naval architects to be acquainted with all which has been written on the subject, even if it be but to know that there is little or nothing useful in a great part of it: such will be the result of an examination of the mechanical methods of construction. With our present degree of knowledge of this science, such systems can never again come into extensive practice.

If all the principles of naval architecture were developed, and if correct methods of calculating and combining their results, were capable of being obtained, and applied under all circumstances of design, a system might be formed for general practice in the construction of ships. This has been said by an eminent foreign writer on the subject, and, as an abstract proposition, is evident to all: it would be the possession of a general expression capable of being applied to a problem under all circumstances. It is not the truth of the proposition which is denied; it is the impossibility of practically accomplishing this object, which is insisted on. Even if it were possible to form a system combining all our present knowledge of the subject, any further development of the laws of nature which govern the motions of a ship, would render it incomplete, and consequently untrue in practice. But a momentary glance at the immensity of the subject represses the hope of such an object being attainable. Must we conclude, then, that it is ignorance of the extent of the subject which leads men to form these narrow and arbitrary mechanical systems of construction? In some cases it is so;—it may, perhaps, be generally so,

The question then arises, what is the proper method of conducting the design of a ship? Common sense and a just view of philosophy teach us, that every machine should, as far as our knowledge of the subject enables us, be given such properties as will adapt it to its particular service; and that such properties are to be sought for by the application of established principles of science to its construction. The principal qualities which a ship of war should possess are,—that it should stow all the necessary stores and furniture, carry its guns at a sufficient height above the water to be used in all circumstances in which they may be required, sail fast, beat well to windward, answer the helm readily, and work easily at sea. The particular service in which the ship is to be generally employed, with the nature of the seas in which it will be generally navigated, must of course influence the relative qualities of the design. The magnitude, relative dimensions, and form, are determined by the constructor in relation to these qualities. The different elements of the design which affect these qualities, should be compared with the corresponding elements of ships of the same class, of which the behaviour under different circumstances at sea has been carefully observed.

It may be safely affirmed, that our present state of knowledge of naval architecture, at least enables us to attribute to the different elements of the design, the effects they produce on most of the principal qualities of a ship. According as the ships which are examined, in order to form the data for comparison with the intended design, have been found to possess good or bad qualities, so must the elements of the design be determined in relation to them: where any quality has been deficient, those elements on which it depends must be increased; and where any quality has been found too great, the elements on which it depends must of course be diminished. Such necessary alterations can be correctly ascertained by calculation founded on mathematical principles, for most of the qualities of a ship; that they cannot for all, is certainly to be lamented: but it would be absurd in a constructor to pretend to a degree of knowledge which is certainly not possessed at present. It is impossible for a constructor to design a ship under any data which shall sail with the greatest possible velo-

city; but it is certain that he can design a ship which shall possess any degree of stability that may be required. There are but few qualities, which cannot be given by a constructor to a ship in any degree required; and there are no qualities *possessed* by any ship, which have been carefully observed, and whose dimensions and form are known, and consequently whose elements can be strictly calculated, which cannot be transferred, with such a degree of probability as to amount almost to certainty, to another ship. There can be nothing remarkable ln the design of a ship, which may not be discovered by carefully analysing its elements; by which its qualities may always be attributed to certain and known causes.

When a constructor has determined the different elements of his design, he makes a drawing as nearly as he can, agreeably to them; the elements are then calculated, and the dimensions or form altered if necessary, till the intended results are obtained.

In making the first rough draught of the design of a ship, the principal dimensions and place of the midship section are first assumed according to the knowledge and judgment of the constructor. The midship section, with two or three sections forward and abaft, the load-water section, with two or three horizontal sections below it, and the heights and half breadths of the main breadth and top breadth lines, are then drawn by hand, and some approximate calculations made, to find whether the draught is generally in accordance with the intentions of the constructor, as to the principal elements of the design: such as its displacement, the position of its centre of gravity, and the stability. The necessary alterations are then made, and a more complete draught formed, which is subjected to a stricter examination of its elements, which are correctly calculated, and compared with the calculated elements of other ships, in reference to their known qualities. A draught of the masts, yards, and sails, should then be made, in relation to the dimensions and form of the ship, which should be compared in this as well as in all other respects, with the designs of ships of approved character.

All the knowledge and experience of the constructor are, by these means, brought into practice in the design of the ship.

The whole of this process is conducted on known principles of science, and all results are subjected to the safe test of comparison. There is no pretension to secret knowledge, no particular curve introduced into the system arbitrarily, without knowing anything of its physical properties. Every thing in the design of a ship should be determined in reference to past experience, and on intelligible scientific principles.

If it is said, that good ships have sometimes been built by such empirical methods of construction as have been described, it is admitted, that by chance they have; but by chance, also, have many very bad ones been constructed by the same methods. Because the science of naval architecture is not yet more fully known, should we therefore neglect the advantages which the principles that are known afford us?—Should we not rather duly appreciate what is known, apply such knowledge, as far as it is fairly proved, to the construction of our ships, and, by the same means as have been successful in advancing other sciences, seek for the improvement of naval architecture?

It may however be confidently asserted, that this science is sufficiently understood in this country to enable us to build, with certainty, ships possessing all the essential qualities of safety and general efficiency. Greater excellency in the science of naval architecture can be expected to be attained, only in the extension of our knowledge by an experience of the qualities and elements of ships already built, and by a legitimate application of mathematical science to the subject. Such a mode of treatment, we doubt not, will be as successful in naval architecture as it has been in other sciences: if the improvement be slow, it will be only on account of the extent and difficulty of the subject. The knowledge of this science has certainly greatly increased in this country, within the last twenty years; and we have every reason to believe that its progress will be accelerated. We trust that, should another war take place, British ships will be built from British designs, and will be found worthy of being manned by British sailors.

Art. II.—*A Method of connecting the Frame Timbers of Ships; together with a Mode of forming Decks.* *By* Mr. W. Henwood.

Excellence in ship-building principally consists in making a ship strong, light, and durable. These qualities are compatible one with another. Strength combined with lightness, is favourable to durability; and strength, in a ship, depends much more on the manner of disposing and connecting, than on the quantity of the materials of which the hull is composed.

It is of primary importance that ships should be sufficiently strong to answer the purpose for which they are designed; and it is proper they should have an excess of strength, rather than a deficiency. It should still be considered, that the greater the quantity of timber, iron, and other articles, actually made use of in building ships, the greater must be their original cost, the greater must be the expense of keeping them in repair, and the more unsuitable must they be found for active service at sea.

Our ships of the line, as at present built, are, it is presumed, sufficiently strong. That they are also as light as it is possible to make them, without a sacrifice either of strength or of durability, is not considered equally certain. The object of the writer is to endeavour to show, that ships of war, of the larger classes, might be rendered as strong as they usually are, with a much smaller quantity of materials.

The frame timbers of ships afford that strength to their sides, by which they sustain the effects of the rolling motion at sea. These timbers are united in separate sets, or frames, by means of bolts, and by a coak in each abutment. The strength of a ship depends, in some measure, on that of the connexion of the frame timbers one with another.

When a ship is much heeled, by the power of the wind on the sails, the efforts of the inclining force, and of the weights on board, have a tendency to diminish the curvature of the vertical transverse sections of the lee-side, and to increase the curvature of those of the weather-side. This straining of the

sides is similar to that which is experienced by a beam, supported near the middle, and sustaining weights towards its ends. The buoyancy of the water may be considered as the fulcrum, acting at the centre of gravity of the displacement; the force of the wind on the sails acts on one side of the fulcrum, and the whole weight of the ship, supposed to be collected at its centre of gravity, acts on the other side.

A beam composed of three or four pieces of timber would, if its parts were connected as frame timbers, be much weaker than if they were united in close contact, and coaked together in the usual way. And in the same manner, the sides of a ship would be much more capable of sustaining the violent efforts of rolling, if the timbers of each frame were united as securely as the parts of a beam. That the frame timbers have always been found to work, more or less, is proved by the fact, that timber or planking has invariably been placed on the insides of ships, to confine the abutments of the timbers.

Were the frame timbers of ships to be united in the same manner as the parts of a beam, (those of each frame being coaked together, and the upper end of each timber being fitted with a bill into the lower end of the timber above, the bill being square to the side of the timber,) there would be so small a degree of this kind of working of the buts of the timbers, even in the most trying circumstances in which a ship can be placed, that it would cease to be an evil, and the timber or planking hitherto employed in the holds of ships to confine the abutments, would be rendered unnecessary.

By connecting the frame timbers in this manner, the spaces would be twice as large, but only half as many in number, as they now are, if the dimensions of the timbers should remain unaltered. And as the durability of the frame timbers is probably in some measure dependant on their arrangement, it is proper to consider whether they would be more obnoxious to decay if those of each frame were joined in close contact, as has just been supposed. It may first be mentioned, that many of those timbers, in ships of the line, are either contiguous or so near each other that there cannot be a free circulation of air over their surfaces.

It has been stated by Dr. Hales, that "the closer the tim-

bers are to each other, provided they are not so close as to exclude any degree of air, so much the sooner are they apt to decay: the confined air between the outer and inner linings of a ship, and between the outer planks and ribs, destroys those timbers, and corrodes the treenails asunder like *aqua fortis:* so that whenever we see timbers, when laid open, decayed, we may be sure it has been done by that most subtle and powerful dissolvent,—close, confined, putrid air." And, according to Dr. Henry, "even moist wood, when excluded from the air, shows very little tendency to decomposition."

The justness of these observations has always been verified by the appearance of ships when opened for the purpose of being repaired. It is uniformly found, that where the air has been *perfectly* excluded, the timbers are in a sound state; and that, in proportion as a free circulation of the air upon the surface of timbers exposed to its influence has been obstructed, so much the more rapidly have those timbers decayed. Were the timbers of each frame to be placed in contact, in the manner above described, the air might easily be excluded from their contiguous surfaces, by chincing the joint, and injecting a mixture of tar and cement between the surfaces; and the increased width of the spaces between the frames would afford a more free circulation of air in all the openings. Thus the whole of the timbers would either be more completely exposed to the air than they are at present, or they would be preserved from the pernicious influence of impure air; and this would certainly have a tendency to increase their durability. The correctness of this conclusion rests on the fact, that a complete exclusion of air from the surface of timber, and an uninterrupted circulation of air upon it, are both conducive to its preservation.

According to the usual method of framing ships, one-fourth of the frame timbers are completely unconnected with the planking of the topsides, and afford the latter no effective support; another fourth of them have no connexion with the planking of the topsides above the lower sides of the upper deck ports of two-decked ships, or middle deck ports of first-rates. This want of union between the lower and the upper timbers of the frame is probably one cause of that variation of

the angles formed by the decks and sides, which takes place in a ship when rolling in a sea, or when much inclined by a press of sail.

If the frame timbers were to be coaked together, those under and above the parts would be connected each with its adjacent port timber, and, if necessary, with the portsills; and the latter might be tenoned or coaked to the port timbers. The whole of the timbers of a ship's frame would thus be rendered equally subservient to the strengthening of the topsides. The sides of ships, and especially their topsides, would thus evidently be rendered more inflexible; and, as there would be less working of the frame timbers when a ship is rolling, the union of the beams to the sides would be less rapidly weakened. The topsides of large ships are comparatively weak; and it is probable it will be requisite to strengthen them considerably, if heavier guns of large calibre must be generally made use of in the Royal Navy.

If the connexions of the frame timbers were to be produced by means of coaks, the frame bolts might be dispensed with: the treenails and bolts which pass through the outside planking would maintain the timbers in an inseparable contact one with another. Those bolts, when placed as they usually are, in unseasoned timber, are extremely pernicious: the oxidation of the metal injures the timber, and decomposition, both of the bolts and the wood which surrounds them, is the consequence. Also, they are not so well adapted as coaks to resist the working of the timbers; and they may, in some circumstances, be an occasion of a deficiency of strength to a ship which ought not to manifest any symptoms of weakness.

Were the frame bolts to be omitted, there would be no treenails driven short, nor would bad holes for other fastenings be made, as is now but too frequently the case. It often happens, that planks lying in the range of the frame bolts have two or three, and sometimes several treenails driven less than half way through the timbers, owing either to the carelessness of the workmen, or to the difficulty of boring holes clear of those bolts. Such an obstruction in the way of properly fastening the planking ought, if possible, to be removed.

In putting the frame timbers together, they might be lashed

to each other, or connected with deals, until the frame should have been hoisted and arranged on the ribbands, and the foremost or the aftermost half of each frame secured to the ribbands. The remaining timbers of each frame could then, if necessary, be separated from those attached to the ribbands, and fastened likewise; so that every timber might be thoroughly seasoned.

In time of war, it may sometimes be necessary to build ships with unseasoned timber. This method affords a means by which the progress of seasoning a ship's frame might be rendered more rapid.

According to the present mode of framing ships, the ends of the timbers are tarred or painted, and kept in close contact during the period of seasoning: so that the abutments, which ought, if possible, to be more completely exposed than any other parts of the timbers, are quite excluded from the influence of the atmosphere. As it is from the ends of timbers the vegetable juices most freely evaporate, painting the abutments before the seasoning has been completed must, in a great degree, prevent the escape of the elements of decomposition from the heart of the timber.

By framing ships in the way which has been suggested, this evil might easily be remedied. Half of the timbers of each frame might be so secured or suspended on the ribbands, that the air would have access to their heads and heels; and when the ship had stood to season one half of the intended period, the abutments so seasoned might be brought into contact, and the remaining portion of the timbers of the frame separated to season in a similar manner. The performance of this operation would not be difficult: the half of each frame suspended on the ribbands would be supported by the other part, the timbers of which would remain in contact. The question is, whether the probable advantage of a more complete evaporation of the vegetable juices from the ends of the timbers would be an equivalent for the trifling expense for workmanship, which separating and replacing the timbers would occasion.

If a ship's frame, or any part of it, were to be formed of newly-felled timber, it might, perhaps, be as thoroughly seasoned by this expedient as the frames of ships are by the usual method. And if a complete and rapid seasoning of the frame

of a ship could thus be effected, the practice of keeping a large store of timber in a sided state for future use may not be regarded as absolutely indispensable.

What has been stated appears to show that an advantage would be gained, in point of durability, by connecting the frame timbers of ships in the manner proposed; and it is most obvious that this method would increase that strength of a ship by which she sustains the effects of the rolling motion at sea. It is, therefore, of importance to observe, that if ships as now built are sufficiently strong, the dimensions and the weight of the timbers of the frame might be diminished; because an equal, or perhaps a greater, degree of strength could be produced with a considerably smaller quantity of materials.

The subject of ships' decks will now be adverted to.—A few observations will, in the first place, be made on the present mode of constructing decks and uniting them to the sides. An endeavour will then be made to show, that the decks of the larger classes of ships might be rendered considerably lighter than they are; and that, at the same time, a much more simple and permanent connexion might be formed between the ship's sides.

In order to judge of the excellency of the present method of connecting the beams with the sides of a ship, it will be proper to premise the following particulars.

The lower deck beams of a ship of the line are some of the largest pieces of timber made use of in ship-building: in a first-rate, they are 17 inches square. The ends of the beams are secured to the ship's sides, by being coaked and bolted to the shelf and waterway, and by an iron knee at each end. The coaks in the shelf are sunk two inches into the lower sides of the beams, and those in the waterway two inches into their upper sides. The coaks are the principal and most effective means of preventing a separation of the beam-ends from the sides. As, however, they do not penetrate into the beams more than one-fourth of their depth, an equally strong union would be produced if the beams were but half as deep as at present. The bolts which pass through the waterway beams and shelf, serve to keep those timbers in close contact, and to render the resistance afforded by the coaks to a separation of the beams from the sides of a ship, as great as possible.

The iron knees appear to be intended both to strengthen the union of the beams and sides, and to preserve the angles formed by the beams and the vertical transverse sections of the sides unvaried, when the ship is rolling. It seems generally supposed that the knees are of use in opposing the latter effect, when they clasp the beams: the transverse strength of the bolt in the side-arm of a knee is about equal to that of those in the beam-arm; and as the bolts are, in this case, acted on transversely, they appear calculated to afford a powerful resistance to an alteration of the angles of the beams and sides. This question will be more fully considered hereafter.

It has been suggested to the writer, that when a ship has returned from sea, an examination of the scuppers will always show whether there has been much angular motion of the beams; for whenever this has been produced, the scuppers must, if originally made whole, inevitably have been broken. That it is considered impracticable to prevent the angular motion of the beams, or that it is found the iron knees do not prevent it, appears probable from the circumstance that, within these few years, it has become the practice to form the scuppers in two parts, one being placed within the other; so that whatever degree of angular motion of the beams and sides may eventually take place, the scuppers cannot be injured.

The union of a knee to the side of a ship is produced entirely by the strength of the heads of the bolts through the side; and this is by no means adequate either to the transverse strength of the bolts through the beam-arm of the knee, or to the strength of the knee. If, by an omission of the coaks in the end of a beam, its connexion with the side should be dependant on the knee, it is evident that, on the working of the beam, the upper part only of the side-arm of the knee would be drawn off from the ship's side, and that the strain would be principally on the head of the upper bolt, which would of necessity give way before the heads of the lower ones could be brought fully into action. The fastening of a knee to the side of a ship, may therefore be considered as arising chiefly from the head of the upper bolt, which must be of inconsiderable strength, compared either with the transverse strength of the bolts through the beam-arm of the knee, or with the secu-

rity afforded to every beam by the coaks and bolts in the shelf and waterway. And it hence appears there is ground to suspect that the knees are not, in reality, of so much utility in strengthening the union of the beams with the sides as may have been supposed.

This may be made more apparent by mentioning, that the heads of bolts for iron knees, by being made too brittle, are occasionally broken off by the violence of the concussion to which they are subjected whilst the workmen are driving on them; and it is not improbable that the heads of all the bolts are, in some measure, weakened in the same manner. It seems, on this account, that it would be unsafe to depend entirely on the connexion produced by iron knees, when it arises merely from the heads of the bolts, in any case where strength is of much importance; and it is presumed it would be advisable to dispense with it altogether, for the purpose of securing the beams of ships, if they could be connected with the sides by simple and more efficient means. The weight of the iron knees for the lower, upper, and quarter-decks, and forecastle, of an 84-gun ship, has been ascertained to amount to 559 cwt. 2 qrs. 25 lbs., or, in round numbers, 28 tons. This is a great weight to be attached to the topsides, and the expense for materials and workmanship is great also.

In addition to these fastenings, the side-binding strakes cooperate with the shelf and waterway in preventing a separation of the beams from the sides. The latter, however, are much more effective in this respect than the former; and they might be rendered sufficient for connecting permanently the sides of a ship, independently of the binding strakes. And, as these strakes are cut half-way through, in order to secure them over the beams, and as the spaces between the beams and half-beams are commonly about 18 inches, the bolts of the binding strakes are frequently but a few inches from the end grain of the wood, and cannot, therefore, in general, be driven so tight as to render these strakes of material utility in strengthening the union of the beams with the sides.

It may be observed, in a word, that scarcely any of the bolt fastening at the ends of the beams can be brought into a full degree of action, until the coaks in the waterway, beams, and

shelf, have been by some means destroyed; and that, whenever the connexion of the beams and sides is greatly dependant on bolts through iron knees or side-binding strakes, there must be a continued working of the fastenings, which must rapidly diminish the strength of the union between the sides of a ship. Coaks are certainly the most efficient means of preserving the sides in their original positions, with respect to each other.

The quantity of security afforded by the coaks in the ends of the beams of an eighty-four has been estimated in the following manner:—

	Feet.	Ins.
The length of the orlop deck is	166	0
The space occupied by 29 beams, each sided 15 ins.	36	3
— — 28 half do., each sided $10\frac{1}{2}$ ins.	24	6
— containing coaks is	60	9
— in which there are no coaks is . . .	105	3
The length of the gun-deck is	193	6
The space occupied by 33 beams, each sided $16\frac{1}{2}$ ins.	45	$4\frac{1}{2}$
— — 32 half do., each sided $10\frac{1}{2}$ ins.	28	0
— containing coaks is	73	$4\frac{1}{2}$
— in which there are no coaks	120	$1\frac{1}{2}$
The length of the upper deck is	195	0
The space occupied by 34 beams, each sided 15 ins.	42	6
— — 33 half do., each sided 9 ins.	24	9
— containing coaks is	67	3
— in which there are no coaks	127	9

	Feet.	Ins.
The length of the quarter-deck and forecastle is .	198	0
The space occupied by 46 beams, each sided $9\frac{1}{2}$ ins.	36	5
— — 4 half do., each sided 7 ins.	2	4
— containing coaks is	38	9
— in which there are no coaks	159	3

The great proportion of the length of each deck, thus manifested to be, in a great degree, unconnected with the sides of a ship, is sufficient to prove, that if the strength of union which is produced between the sides by means of coaks could be uniformly distributed through the whole length of each deck, instead of being only in the ends of the beams, the connexion of the decks and sides of a ship would be about twice as complete and permanent without any knees whatever as it is at present.

It seems owing to the magnitude of the principal beams of large ships, that it is so difficult, or impracticable, to apply an adequate degree of fastening to their ends. It certainly does not appear to be necessary that the beams of ships should be of such great depth as they usually are, for the purpose merely of uniting the sides: whether, if they were of less depth, they would be sufficiently strong for sustaining the guns, will subsequently be inquired.

Respecting the fitness of the combination of beams and deck flat, for forming a substantial basis for the cannon, it is to be observed that the strength of a deck is far from being the same at every point. In the intermediate vicinity of each of the principal beams, a deck is very much stronger than in some other parts. The strength of a deck is here supposed to be estimated at the middle between the pillars and clamps, which is the weakest point of an athwart-ship line. Two transverse lines might be drawn in midships, on the lower deck of a ship of the line, 3 or 4 feet apart, and the strength of the deck at the weakest point of one of those lines would be about four times as great as that at the weakest point of the other. It does not surely require

to be demonstrated, that, if two positions, *a* and *b*, be taken on a deck in a fore and aft line, and if the deck is sufficiently strong at the position *a*, it must be uselessly and absurdly strong at *b*, where it is capable of supporting four or even six times as much weight as would produce a fracture at the former position.

A mode of constructing the decks of ships will now be described, according to which there would be an uniform and general distribution of coaks throughout the whole length of each deck: this would render the union of the sides of a ship much stronger than it is at present; the decks would be uniformly and sufficiently strong everywhere; they would consist of a much smaller quantity of materials than is now required for their formation; and other advantages, highly important, would also be obtained.

The principal portion of the weight of the decks and guns, is sustained by the clamps and shelves, at the sides of a ship; the remainder is supported by the pillars under the beams. As the force of the water on every point of the bottom of a ship is in proportion to the depth below the surface, there must be a great excess of buoyancy on the lower part of the body, near the keel. These two forces,—the weight on the clamps, and the power of the water,—in counteracting each other, must produce a transverse strain on the sides of a ship, which must be greatest in midships, at something less than half way up from the keel to the water's surface. If a part of the enormous pressure which acts downward on the clamps, could be transmitted directly to that part of the body near the keel, which sustains the greatest pressure of the water, the indirect reciprocal counteraction of these forces, which must operate powerfully and constantly to impair the strength of a ship's hull, would, in some measure, be removed. And this might be effected, if a row of pillars were to be fixed at the distance of a few feet from the middle line, on each side of the ship, instead of those now placed on the keelson. The employment of two ranges of pillars would render the beams virtually shorter, because the points of support would be nearer together; and it would, therefore, authorise a diminution of their depth. Also, that part of the pressure of the water on the keel and

lower part of the surface of the bottom, which sustains the weight incumbent on the pillars, would be counteracted at two points, instead of at one only, as at present.

In the construction of the decks now to be described, two rows of pillars are requisite: they are designed to be placed under two shelves, which extend in a fore and aft direction from head to stern, at the sides of the hatchways. The midship shelves would be placed as much above the level of those at the sides of the ship, as would be required by the convexity, or round-up of the deck.

The decks would consist entirely of thick-stuff, placed athwart-ship upon the side and midship shelves. Fig. 11, plate 2. is a part of the midship section of a ship of 84 guns, with the decks drawn in the manner described. Fig. 12. is a part of the plan of the lower deck. The letters *b*, *b*, mark the beam pieces; *f*, *f*, the filling pieces; and *m*, *m*, in both figures, the midship shelves. The ends of the thick-stuff would be in contact with the frame timbers, as the ends of the beams are; except a small part of that of the orlop deck, which would come against the diagonal framing. Every other piece of thick-stuff on the larboard side, which is not in the wake of a hatchway, or mast-hole, would extend as far as the starboard midship shelf, so as just to rest upon it; and vice versa. These pieces, for the sake of distinguishing them, might be designated beam-pieces; as every consecutive two of them, by being coaked and otherwise fastened together, would form a beam; which would be coaked to the side shelves as beams are at present, and also to the midship shelves. The beam-pieces would have their broadest ends in midships; one edge of each piece would be straight, and the other edge, for the sake of economy in conversion, would be tapered from the but of the contiguous beam-piece, towards the ends, or towards the top end only. Thus the form of the pieces would be similar to that of top-and-but planking. The remaining pieces of deck thick-stuff might be denominated filling-pieces. Those between the beams would be tapered from end to end, and would have their broadest ends at the sides of the ship. Those in the wake of the hatchways might be tapered or not. The pieces of deck thick-stuff at the fore and after sides of the hatchways, could be termi-

nated at the middle line, and be coaked to the shelves, and to ledges fitted between those in midships. Where the hatchways and ladder-ways are adjacent, a beam would be placed between them as at present; and, in order to connect its parts very securely, they might be coaked to a ledge between the midship shelves, and to a piece fitted between the comings.

The beams would be got in place as soon as the side shelves should have been wrought; they would be coaked to these shelves for the purpose of connecting the sides of the ship; and they would be kept to their height at the middle line by a ribband, until the midship shelves should have been wrought on their under sides, and coaked to them and pillared. The filling-pieces would be coaked to the side and midship shelves: they would, however, not be wrought until it became necessary, in order to proceed with other parts of the structure; as by leaving them out as long as possible, a sufficiency of light and of air would have free access to the hold.

All the deck thick-stuff should be wrought of as great breadths, as the timber of which it might be formed would admit: the waste occasioned by reducing timber to make it of a given scantling, could thus always be avoided.—Timber which would make beam-pieces of the usual size, might be applied for such decks very advantageously. All that it would be necessary to observe, would be, that each piece should not be of less breadth, at half-way between the side and midship shelves, than a given definite proportion of the distance between the points of support.

A pillar might be placed at the middle of each space between the ports, underneath the side shelves, to sustain the pressure of the decks above, in lieu of the chocks through which the iron knees are bolted.

The deck hooks and transoms could be wrought in such a manner, that the foremost and the aftermost pieces of the side shelves might be scarphed to them respectively, as the shelf pieces are now to each other. This would render the side shelves complete internal hoops to a ship, and would be condusive to a general diffusion of strength. These hooks and transoms might be made of such siding, that they would form a part of the upper side of the deck.

The midship shelves could be so constructed as to form the sides of all the hatchways: they would, in conjunction with the deck thick-stuff, produce sufficient strength at the mast-holes, and would render the riding bitts, and the bowsprit step, and capstan partners, abundantly firm. And as each end of the midship shelves could be strongly united to the deck hooks and transoms by an iron plate; or by means of a piece of knee-formed plank coaked on their under sides, they would produce a very powerful connexion between the ends of a ship. The thickness of the midship shelves might be about equal to that of the deck thick-stuff; and their breadths should be always sufficiently great for coaking and fastening the deck thick-stuff to them.

Such decks would have waterways of smaller dimensions than the present ones. They might be formed of thick-stuff; of the same siding as the side shelves, and of as great a moulding as would be convenient for conversion, and for running out the guns. Their several pieces could be scarphed flatways, and be coaked to each other, and to the thick-stuff or plank placed behind as fillings, on account of the tumbling home of the sides. This would render the waterways internal hoops also. An angular surface could be formed upon the deck thick-stuff, to receive the waterways; so that there might be a seam for the caulking, of the same depth and direction as is now formed in all cases. The waterway would be coaked to each piece of deck thick-stuff, and bolted through the deck and shelf, and to the sides of the ship: and as the up-and-down bolts, although proportionally smaller, would be much more numerous than at present, the waterway would be kept in a permanent contact with the deck. This would effectually prevent leaking at the waterway seam.

The comings and head ledges could be let down into the deck thick-stuff a sufficient depth for caulking round them.

That these decks might not be unnecessarily thick, and that the greatest degree of strength might be obtained with thick-stuff of a given breadth and depth, it would be proper to connect the beam and filling-pieces in such a manner, as that they would support each other. This could be done by coaking them together at the edges; but then it would be requisite

that the coaks in one edge of every piece should be doubly sunk. It might be done by laying a deck-flat upon the thick-stuff; or by lining the under sides of such decks. But it is considered that a better way of uniting together the beam and filling-pieces, would be to place two diagonal keys (marked *k*, *k*, in figures 11 and 12,) in every joint between the side and mid-ship shelves; spacing them so as to divide the distance between those shelves into three equal parts. These keys should be let into the edges of each piece of thick-stuff, about an inch, or an inch and half, or so much, that each piece if supported at its ends after the scores were cut out, would bear as much weight suspended from the place of the score, as it would support at the middle of its length. Diagonal keys would produce a very strong connexion between the beam and filling-pieces; and they would prevent the working of any part of such decks, either in a vertical, or in an athwart-ship direction. If, instead of diagonal keys, a deck-flat of planks or deals were to be placed upon the thick-stuff for the purpose of connecting it, the fastening the flat might weaken the deck; the whole weight of the decks would be considerably increased; it would be necessary to place the guns of the uppermost decks several inches higher; it would be much more difficult and expensive to replace any part of a deck that might be worn or decayed; and, what is perhaps of much greater consequence, the unavoidably imperfect contact of the deck-flat and thick-stuff, would engender decay. A peculiar advantage of the method in question would be, that by having no deck-flat, there would be no tendency of the materials to rot through being situated one upon another. Every part of such decks would be exposed to the air, except that in contact with the shelves and waterway; and from this the air might be perfectly excluded.

Respecting the connexion of the larboard and starboard sides of such decks, it may be proper to mention, that it is requisite it should be at least as strong, as the union of the decks with the sides of the ship. As many coaks might be used to join the beam-pieces together, as would alone produce this degree of strength. But, as it would be very easy to connect all the beams one with another, by means of a small piece of wood, inserted as a key, in the joint of every two contiguous beams, at the middle line of the deck, (as shown at *z* in figures 11 and

12,) it would not be necessary to make use of more coaks in uniting the beam-pieces, than, together with these keys, would render the union of the starboard and larboard sides of the decks sufficiently powerful. By making these keys of hard and tough oak, and placing their ends in contact with the end grain in the scores cut to receive them, they would present an insuperable resistance to a separation of one side of a deck from the other, and to a working of the beams in an athwart-ship direction.

It may now be observed, that the coaking of the whole length of each deck to its shelves and waterways, would evidently render the union of the decks and sides of a ship very much stronger than it is at present; and by connecting the beam and filling-pieces together with keys, a deck would be, as nearly as is possible in practice, of uniform and equable strength throughout.

The simplicity of this method of constructing a deck may just be adverted to. Instead of beams, half-beams, carlings, diagonal ledges, binding strakes, and deck-flat, requiring a large quantity of fastening; the midship shelves, and the deck thick-stuff, with a comparatively small quantity of fastening, will form a deck as serviceable and substantial as the present decks.

Having described a mode of constructing decks, which appears in many respects preferable to the usual method, it will be proper to state some particulars respecting the strength of beams, and the weights which those of ships are required to sustain, as data for determining the thickness and mean breadths of pieces of thick-stuff, for forming the lower deck of a ship of the line.

To ascertain satisfactorily what ought to be the dimensions of pieces of timber to sustain a given weight, recourse must be had to the results of experiment. Buffon's experiments on pieces of timber of large dimensions, are apposite for the object in view;—to determine the requisite sizes of beams for the decks of ships.

The distance between the side and midship shelves of the lower deck of an 84-gun ship, would, in midships, be 17ft. 6ins. This is very nearly the length of the beams in the following

experiments of Buffon, taken from page 43 of Barlow's "Essay on the Strength and Stress of Timber." These beams were supported at each end, (not fixed,) and the breaking weights were applied at the middle.

Length of beams.		Size square.	Breaking weight.	Mean weight
feet.	ins.	ins.	lbs.	lbs.
17	2	7.5	11944	11836.
17	2	7.5	11729	
17	2	8.57	18078	17620
17	2	8.57	17163	

To find the strength of a beam 17 ft. 2 ins. long, and 8 ins square, it is sufficient to make the following proportions.

$$\overline{7.5}|^3 : 11836 :: 8^3 : 14360$$
$$\overline{8.57}|^3 : 17620 :: 8^3 : 14330$$

Assuming, then, that a beam 17 ft. 2 ins. long, and 8 ins. square, requires 14330 lbs. to produce a fracture; a beam of the same length, 12 ins. broad, and 8 ins. thick, will require half as much again, or 21495 lbs. when its ends are merely supported.

To find the strength of a similar beam by means of Mr. Barlow's formula, according to which the breaking weight W is $= \frac{4\,a\,d^2 S}{l}$; where a represents the breadth of the beam, d its depth, l its length, and S, the resistance of a rod an inch square; taking the mean value of S from the experiments on English oak, on page 181 of Barlow's Essay, we have $W = \frac{4 \times 12 \times 64 \times 1426}{206} = 21265$ lbs. This beam therefore, according to Mr. Barlow's theory and experiments, will bear 230 lbs. less than it was found to sustain by Buffon. Experiment has proved that the larger the beam, the greater is the excess of the weight required to break it, above that which theory indicates. Presuming then, in finding the strengths of large beams, that Mr. Barlow's formula will not give a result greater than the true one, it will now be made use of to compute the strength of one of the lower deck beams of an eighty-four.

The distance between the clamps and the pillars in midships, which may be taken as the length of the beam between

the props, is 23 feet; and the beams are 16,5 inches square. The weight such a beam would bear, when supported at the ends, is $\frac{4 \times \overline{16,5}|^3 \times 1426}{12 \times 23} = 41$ tons, 9 cwt. If the ends were to be fixed (and the ends of ships' beams are fixed with great firmness), more than sixty tons would be required to break it; because the strength of a beam, when its ends are fixed, is to that when its ends are merely supported, as three to two. Assuming, therefore, that the longest beam of the lower deck of an eighty-four, with a pillar under it, would bear sixty tons suspended from the middle point between the pillar and clamp, on either side of the ship, one hundred and twenty tons might be suspended from the two weakest points of the same beam without breaking it;—a weight greater, by about twenty-six tons, than the whole weight of the guns and gun-carriages of the lower deck. The shorter beams would bear still more.

It seems reasonable to doubt whether so great a degree of strength is absolutely necessary for the beams of a ship. An eminent naval architect has stated, that the beams of ships must be of such strength as to endure the weight of the cannon and whatever else is to be placed upon them. But if the above calculations be correct, an eighty-four's lower deck beams would, when new, bear fifty times as much weight as is ever placed upon them. The beams must, of course, be sufficiently strong to sustain the guns in time of action, and under all circumstances, as long as the ship may be expected to continue sound and serviceable.

It is presumed the forecastle of a two-decked ship is sufficiently strong to sustain twelve-pounder guns, in time of action, and under all circumstances; and it is therefore considered, if the strength of the other decks bore the same proportion to the strength of the forecastle as the weights of their respective guns, they would be as strong (all things taken into the account) as they ought to be. Also, as the forecastle has a greater convexity or round-up than the other decks, it must invariably receive a more violent shock from the recoil of a gun; and its strength is, on this account, a safe criterion for determining the requisite strength of the other decks.

As the strength of any fabric is only that of its weakest part,

that of the deck-flat, at the middle of the spaces between the forecastle beams, must therefore be considered as the strength of the forecastle. This will now be computed.

The greatest spaces between these beams, in a ship of 84 guns, are nearly or quite 3 feet; and the deck deals are 3 inches thick, and about 9 inches broad. It is accordingly only necessary to find the transverse strength of a fir plank, 3 feet long, 9 inches broad, and 3 inches thick, when fixed at both ends. Making use of the above formula, $W = \frac{4\,a\,d^2\,S}{l}$; where the mean value of S, on pages 184 and 185 of Barlow's Essay, is 1080 lbs.; W is $= \frac{4 \times 9 \times 9 \times 1080}{36} = 9720$ lbs., or 4 tons 6 cwt. 3 qrs. The weight that would be required to break one of the forecastle deck deals, supposing it firmly fixed on the beams, is, therefore, $6\frac{1}{2}$ tons.

Now, as the weight of a twelve-pounder gun and carriage is something less than two tons, and as this weight is sustained in nearly equal degrees by the four trucks of the carriage, a greater weight than half a ton can seldom be brought on any part of the forecastle at the same instant; and as the weakest part of the forecastle of an eighty-four requires $6\frac{1}{2}$ tons to produce a fracture, every part of it is about thirteen times as strong as would be sufficient merely to support the weight of its guns. It is inferred that, as a beam 17 feet 2 inches long, 12 inches broad, and 8 inches thick, will bear $9\frac{1}{2}$ tons when its ends are supported, and therefore $14\frac{1}{4}$ tons when its ends are fixed,—and as the weight of a 32-pounder gun and carriage is less than $3\frac{1}{4}$ tons, and consequently a greater weight than $\frac{13}{16}$ of a ton can seldom be placed on the weakest part of the lower deck of an eighty-four at the same time: this deck, if formed of thick-stuff 12 inches broad and 8 inches thick, laid athwart-ship according to the method which has been described, would be more capable of supporting the cannon upon it than the forecastle is of sustaining its guns, in the proportion of 17,5 to 13, and, therefore, more than sufficiently strong under all circumstances. But as the beam and filling-pieces could, in midships, be as much as 18 inches broad, at half-way between the side and midship shelves, the above ratio would be, in fact, 26,25 to

13; which shows that such a deck would be twice as strong in proportion to the weight of the cannon placed upon it, as the forecastle is in comparison with the weight of twelve-pounder guns.

As the beam and filling-pieces might be so connected, by means of diagonal keys, that they would support each other, it seems reasonable to suppose that a less thickness than eight inches would afford as great a degree of strength as is requisite for the gun-deck of a ship of the line. But, as an excess of strength in any part of a ship is preferable to a deficiency, it will be assumed that eight inches is a suitable thickness; and in support of this position it is only necessary to observe, that every part of such a deck would be much stronger than the weakest parts of the lower deck of a line of battle ship, as now constructed, and that this is the principle upon which this method is founded.

It is now of some importance to consider, whether the angular motion of the decks and sides would be effectively resisted when a ship rolls deeply in a hollow sea, or is much inclined under a heavy press of sail, if the decks should be formed in the way which has been described;—according to which, there would be no knees at the sides.

The simplest illustration of the manner in which a ship is acted on in those circumstances, is considered to be that already given,—of a lever, supported on a fulcrum, and loaded with weights towards its ends. The ship is the lever, the centre of gravity of the displacement is that point of this lever, at which the buoyancy of the water or the fulcrum is applied; the gravitation of the weight on each side of the vertical and longitudinal plane passing through this point, combined with the effort of the wind on the sails, are the forces which keep this lever in equilibrium.

If we conceive a ship to be in an inclined position, either when rolling in a boisterous sea or when under a press of sail, and consider, that the centre of the upward pressure of the water, is situated in a vertical line on the lee-side of the vertical through the centre of gravity of the ship, and that the whole force of the water may be supposed to act upwards at its centre of pressure, it will appear obvious that the gravity of the wind-

ward side is greater, and that of the leeward side is less, than the subjacent buoyancy on each side respectively. The excess of buoyancy on the lee-side must cause it to rise, at the same time that the unsupported weight on the weather-side must cause the latter to descend; and this simultaneous rising and falling of the sides of a ship, during the interval of heeling, is undoubtedly the principal, if not the only cause, of the angular motion of the beams and sides. The action of the wind on the sails, being in a horizontal direction, can have but little, if any, influence in producing such an effect.

When the windward side descends for want of an adequate support from the water, as the guns and iron knees are weights of great specific gravity, situated at the greatest distance from the longitudinal axis round which the vessel revolves, it is evident that, during the time of the descent, the guns and iron knees on the emerged side must acquire a much greater momentum in falling, than any other weights in the ship; and, as the guns rest on the beams, the beam-ends on the windward side must therefore have a tendency to descend at a quicker rate, than the side of the ship to which they are attached. This must tend to diminish the angles which the beams and the vertical transverse sections of the windward side form with each other, and must, in some degree, contravene the tendency, which the falling of the windward side must have to increase those angles. It necessarily follows, that the iron knees of the emerged side of a ship, can never be brought to act with much effect in resisting the angular working of the beams. A ship, when rolling, and even when inclined by the sails, is never at rest: one side is constantly immersing, and the other emerging; and the comparatively great momentum which the guns and iron knees on the emerged side acquire in descending, must continually preserve the knees on this side from being powerfully acted on. The knees on the immersed or leeward side of a ship can be of no other use whatever, than as pillars to support the ends of the beams.

It is mentioned by Mr. Knowles, in his 'Inquiry into the Means of Preserving the Navy,' that "the Malabar, of 74 guns, built at Bombay, brought home, under jury-masts, a large cargo of timber; and as iron-work is expensive, and but indif-

ferently executed in India, all the knees were omitted: the ship, on her passage home, from an excess of stability, was subject to violent motions, and encountered four severe gales of wind; yet there had been no apparent motion or working in the materials for the want of knees." This fact accords with the foregoing reasoning, and with the conclusion derived from it,—that knees cannot be of material utility in preventing angular motion of the decks and sides.

The cause of angular motion of the decks and sides is, as has been stated, the rising of the lee-side and falling of the weather-side during the interval a ship is being inclined. This change in the relative positions of the sides, produces an alteration of the curvature of the vertical transverse sections of the bottom, and a working of the heads and heels of the frame timbers. If, therefore, this working of the abutments of the frame timbers were to be diminished, as it might be, by coaking instead of bolting those timbers together, a change both of the curvature of the bottom and of the relative positions of the sides, and consequently the angular motion of the beams, would be resisted in a direct and most effectual manner. It is chimerical to suppose the angular motion of the beams can be prevented by means of knees at their ends, whilst a change of the curvature of a ship's bottom can be produced by the relative rising and falling of her sides. To prevent angular motion, we must first prevent, as much as possible, an alteration of the relative positions of the sides when a ship is rolling; and this never can be effected by means of knees at the ends of the beams.

It is considered that the powerful connexion of the sides of ships, which would be produced by means of the athwart-ship decks, in conjunction with an increase of strength of connexion of the frame timbers with each other, would render our ships of war, in general, much less susceptible of a change of form, under any circumstances at sea, than they can have been hitherto.

That it is impossible the angular motion of the beams of ships can be totally prevented, is undeniable; because it is impracticable to render a ship perfectly rigid. Should it therefore be considered, that if ships' decks were to be formed of

thick-stuff placed athwart-ships, it would still be proper to apply some means of resisting the angular working of the decks; a substitute for knees might easily be furnished. Considering a deck and a side of a ship as two sides of a triangle, it would only be necessary to fix an iron brace so as to form the third side. The upper end of the brace might be attached to a stout screw, placed in the under-side of the deck, a few inches from the front of the shelf, and the lower end bolted to the ship's side. Any number of such braces might be conveniently applied. It is, however, to be observed, that the direct and most advantageous way of resisting the angular motion of a ship's decks, is to strengthen the connexion of the frame timbers with each other, at that part of the bottom more especially, which is intersected by the vertical and longitudinal plane in which the centre of gravity of displacement is situated, when the ship is inclined considerably from a vertical position.

It is proper to remark, that the weight of the timber and plank now required to form the decks of an eighty-four, is greater than that which would be requisite for forming the same decks in the manner proposed, by about 60 tons. The weight that would be saved by having no iron knees, and by the reduction which would be made of the height of the topsides, would amount to about 100 tons more. A removal of so much weight from the decks and the sides of a ship would be, in fact, a partial removal of the cause of the angular motion of the beams when the ship is rolling.

When a ship is thrown on her beam-ends, or is suddenly inclined to a very large angle, the beams become as props or shores between the sides. In proportion to the tendency which the beams of the same deck have to move parallel to each other, or in proportion to the degree of the change of form which can be produced in the boundary lines of the decks, in this circumstance, so must the ship experience the greater deterioration from the violent straining to which she is then subjected.

To show that if a ship's decks were formed of thick-stuff, that for each deck being of proportionate strength, they would effectually maintain the relative positions of the sides, and prevent a variation of the curvature of the boundary lines

in the above supposed circumstance, it is only necessary to mention, that the area of the longitudinal and vertical section of an eighty-four's lower deck, if formed of thick-stuff, would be to the sum of the sections of the beams and half-beams of the same deck nearly in the ratio of three to two; and that, as all the thick-stuff would be very strongly connected with the side and midship shelves and waterway (as it would be always in the closest possible contact), and as the whole of it could be inseparably conjoined at its edges, by means of coaks and keys, it is obvious that each deck would be, in effect, as an immense board of uniform thickness, inflexible in a direction parallel to its surface. It is reasonable to suppose, that a ship with such decks, would withstand the lateral impulses of waves towards the head or stern with unusual firmness.

The foregoing observations seem to lead to this conclusion: that if the decks of a ship were constructed according to the method which has been described, they would be everywhere of equable strength, and sufficiently strong for supporting the guns; they would produce a much more powerful connexion between the sides of the ship than the present decks; and, as the cause of the angular motion of the decks and sides would in part be removed, and as the frame timbers, by being more strongly united, would present a more powerful resistance to this working, a less degree of it would be produced.

By forming the decks of the larger classes of ships in the manner proposed, they would occupy the smallest possible portion of vertical space; and such a diminution of the whole height of the hulls of those ships might be effected, as would be productive of exceedingly beneficial consequences.

Suppose, in a ship of 84 guns, the lower deck to be formed of eight-inch thick-stuff, and the orlop and the upper decks of seven-inch thick-stuff: the vertical space, or the height taken up by these decks, might be reduced from 4 feet $4\frac{1}{2}$ inches to 1 foot 10 inches. The upper deck could be made of oak thick-stuff in midships, and of fir forward and abaft; since, if the breadths of the pieces of thick-stuff were increased, or if their lengths were diminished, they might be formed of timber of inferior strength. The breadths of the pieces should always be so proportioned to their length, and also to the specific

quality of the timber, that every piecemight be of, at least, a given definite degree of strength. If the quarter-deck and forecastle were formed of six-inch fir thick-stuff, the height occupied by the decks might be further reduced by $5\frac{1}{2}$ inches; and this would make the whole diminution of height amount to just three feet. It might be shown that these assumed thicknesses would be nearly in proportion to the weights on the respective decks.

If the height of an eighty-four-gun ship's hull could thus be reduced, the whole weight of the guns and other articles on the upper deck, together with the deck itself, would be brought down about ten inches; and the quarter-deck and forecastle, with the guns, spars, and other weights upon them, would be situated about 1 foot $3\frac{1}{2}$ inches lower than at present: the heights between decks, and height of the lower deck above the water, remaining unaltered. The orlop deck would be raised $12\frac{1}{2}$ inches, and the depth in hold would in consequence be increased 1 foot $8\frac{1}{2}$ inches; the height between the gun and orlop decks being the same as it is now, to the under side of the gun-deck beams. If the depth in hold is sufficiently great, as without doubt it is, the immersed part of the body might be diminished, as a corresponding reduction of the weight of the ship would be made at the same time.

The weight of the hull of a second-rate, recently built, is about 1880 tons. If the decks of such a ship were to be formed according to the method described in this paper, the weight of the hull would be about one-tenth less; and as the load displacement of such a ship is about 3400 tons, about one-eighteenth part of it would be unnecessary, and might be taken away.

It only remains to take notice of the effect which this diminution of the weight of a ship would have on the stability, and on the resistance of the water.

Reducing the height of the hull above the water would of course make it proper to lower the whole surface of the sails, or their centre of gravity, about $15\frac{1}{2}$ inches; so that it might be at the same height as at present above the uppermost deck. The removal of about one hundred and twenty tons weight from that part of the hull which is above the water, the lowering

of all the batteries except that of the gun-deck, and the bringing down of the centre of effort of the sails, would, together, produce a great increase of stability; and diminishing the depth and the fulness of the immersed part of the ship would, by raising the weights in the hold, occasion a small decrease of stability. The aggregate, however, would be a considerable augmentation of the power which restores a ship to the upright position.

The subtraction made from the displacement of a ship would cause a corresponding diminution of the resistance the ship experiences when moving in the water. This, combined with an increase of stability, which would make it proper to enlarge the surface of the sails, would effect an improvement of the sailing qualities of our ships of war. It seems a necessary consequence, if the moving power be increased or preserved unaltered at the same time that the weight to be moved is diminished, that a greater degree of velocity must be produced: this is undoubtedly the most certain way of improving the sailing qualities of ships, whilst we are utterly unable to prove that any one modification of the form of a ship, within the limits usually observed, is more conducive to velocity than another.

An omission of the iron knees at the sides of a ship, together with a reduction of the height of the hull, which would make the weight of the top-sides of a second-rate at least 70 tons less than it is at present, would diminish the momentum the latter acquires by the rolling motion of the ship. This removal of superfluous weight from the upper works, in conjunction with greater strength of the frames of ships, would authorise as large an increase of their breadths as can be advantageous.

In conclusion, it may be observed, that if the weight of the hulls of our ships of war, were to be diminished in the proportion in which it has been stated, that the weight of the hull of an eighty-four might, a considerable saving of the expense of building them would be the consequence. Supposing the weight of an 84-gun ship's hull could be reduced one-tenth,—and, if the foregoing observations be admissible, this might be done without detriment to the ship,—the cost of the structure would be about one-tenth less: a large proportion of the

articles which would be dispensed with, are some of the most valuable made use of in ship-building. It follows, that a saving of about one-tenth of the capital employed for the production of our larger classes of ships, might be effected.

A real improvement would also be made in the smaller classes of ships of war, and particularly in frigates, if their decks were to be constructed in the manner which has been described. In a frigate of 46 guns, the depths of the orlop, lower, upper, and quarter-deck beams, added to the thicknesses of the flats placed upon them, (which is the vertical space taken up by the decks) make just four feet. This might be reduced about one-half; and each deck would be everywhere as strong, or stronger, than the present decks are at their weakest points.

The advantages of constructing our ships of war, so that they would be lighter, less expensive, and better adapted for active service at sea, would doubtless be of very considerable importance, should the safety of this kingdom be again dependent on the strength of its navy.

ART. III.—*A Method of finding the Centre of Gravity of a Ship. By* MR. W. BARTON, *Student in the School of Naval Architecture.*

(*To the Editors of Papers on Naval Architecture.*)

GENTLEMEN,—The following method of finding the centre of gravity of a ship has not, I believe, been hitherto suggested; thinking it will be found of easy application, and little liable to error, your inserting it in the Papers on Naval Architecture will oblige, Gentlemen,

Your obedient Servant,

W. BARTON.

School of Naval Architecture, Nov. 23d, 1827.

Let the whole, or part, of the guns be run aft; observe the new draught of water, and place of the guns moved; from which (with the draught of the ship,) we may determine the required centre.

Suppose AB, *a b*, (Fig. 13,) the former and new water-lines, D, *d* the former and new centres of gravity of displacement, H and K the former and new centres of gravity of the guns moved. H being in the middle of the extreme parts from which the guns were taken, and K the middle of the space they occupy when moved, (supposing them placed side by side, and pointing athwartships,) and as the curvature of the deck is small, we may, in both cases, take the centre of gravity the same height above it as for a single gun.

Draw DG, *d* N, at right angles to AB, *a b*. The centre of gravity of the ship at first, was in the line DG, but, by moving the guns, it has been brought in the line *d* N. Suppose it to have been the point G: draw GN, KL parallel to *a b*, and HL to *d* N. If w = weight of guns moved, W = weight or displacement of the ship, we shall have

$$w \times \text{KL} = \text{W} \times \text{GN}, \text{ or GN} = \frac{w}{\text{W}} \times \text{KL};$$

and KL being measured on the draught, GN is known. Draw, therefore, a line parallel to *d* N at the distance GN, and its intersection with GD will be the centre of gravity of the ship before the guns were moved.

If the inclination of AB, *a b*, (or, which is the same, of FG, GD,) be small, a slight error in drawing these lines may produce a considerable error in DG. The following method of finding DG will be, in this case, preferable.

Let i = inclination of AB, *a b*; then, since tang. $i = \frac{\text{A}a + \text{B}b}{\text{AB}}$, i is known: draw DE perpendicular to *d* N, and GF parallel to it; and if KL = b, DE = p, both being known on the draught, we shall have $w \times b = \text{W} \times \text{GN}$, or $\frac{w}{\text{W}} . b = \text{GN} = \text{EF}$. Hence, $\text{DF} = p - \frac{w}{\text{W}} b$; but $\text{DF} = \text{GD} . \sin i$,

and consequently $$\text{GD} = \frac{p - \frac{w}{\text{W}} b}{\sin i} = \frac{\text{W}p - w b.}{\text{W} . \sin i}$$

The centre of gravity of displacement D, having been found by the usual calculations, *d* will be easily deduced from it; also, there will be no occasion to move more than the guns on one deck.

ART. IV.—*Method of finding the Centre of Gravity of a Ship. By* RICHARD ABETHELL, ESQ., *Assistant Master Shipwright of H. M. Dockyard at Sheerness.*

THE object of this short essay is, to describe a method of finding the centre of gravity of a ship and its contents, by which the necessity of moving the weights on board, or applying any extraneous forces, in order to produce an inclination from the upright position, is avoided. It will be shown, that sufficient data may be obtained for the solution of the problem, whenever a ship is docked with the under side of the keel deviating from parallelism with the upper surface of the blocks, which is almost always the case. We will suppose, by the falling of the tide in the dock, the after extremity of the keel to come first in contact with the blocks: then, as the tide continues to fall, the after body is gradually forsaken by the water, and the fore body further immersed; a constant equilibrium being maintained between the total weight of the ship, and the pressure of the water against the immersed part of the body, until the ship is aground fore and aft. At any intermediate instant, the ship may be considered as a lever of the second kind, of which the fulcrum is the transverse line or point of contact of the keel and after block, and the power and weight, the weight of the immersed volume and of the ship respectively; each acting in the vertical line passing through its centre of gravity. As we can, by mensuration and calculation from the draught of the ship, easily find its weight, that of the immersed volume, and the perpendicular distance of the line of pressure from the fulcrum; in the equation of the moments, the distance of the vertical line passing through the centre of gravity of the ship is the only unknown quantity, which is therefore readily determined. AN (Fig. 14) represents the water-line corresponding to the floating position of the ship, and KL the observed water-line just previously to the fore part of the keel touching the blocks. The line PBO, perpendicular to AN, passes through the centre of gravity of the displaced volume AFMN, and consequently through that of the ship. Draw QH through the

centre of gravity of the volume KFML, perpendicular to KL, and FG through the fulcrum F, parallel to QH. Then, putting the total displacement AFMN $= V$, KFML $= v$, and GH $= b$; if the line SEO, parallel to QH, be drawn at the distance GE from G equal to $\frac{b\,v}{V}$, it will, as well as PBO, pass through the centre of gravity of the ship, which will be in O, the point of their intersection.

To obtain, from these considerations, a general expression for the perpendicular distance of the point O from the water-line AN, draw AD perpendicular to EG, and meeting it, when produced, in D; and, having calculated the values of AB and GE, put AB $= a$, DE, or DG + GE $= d$, and the angle of inclination between the water-lines AN and KL $= \Delta$; then BO $= \left(\frac{d}{cos.\,\Delta} \sim a\right)\frac{1}{tan.\,\Delta}$; which must be set off upon the perpendicular PBO, above or below AN, according as $\frac{d}{cos.\,\Delta}$ is greater or less than a.

ART. V.—*Tables, methodically arranged, of the Elements, essential in the Construction of Ships of War of all Classes; with Suggestions for their Improvement: but more particularly exemplified in the Class of Frigates. By* JOHN WILSON, ESQ., *of the Navy-Office, London.*

THE following Tables contain the principal elements of ships of all classes or sizes. They were first formed by the writer of this article in 1814, and may be found very useful at this time, when projectors are springing up in all parts of the country, by preventing those mistakes so common to novices in construction: such as making the displacement so small, that the vessel's ports would be so near the water as to render her partly useless as a man of war; or, if this error be avoided, by a common practice of taking the midship section and principal dimensions of another vessel of the same force,

still the same inutility may arise, for want of the proper stability, as this defect will render it impossible, when the ship is sailing on a wind, either to elevate the lee-guns, or depress the weather ones, sufficiently for the shot to hit an object at any reasonable distance.

The tables are constructed in the following manner:—As all the elements of ships are in proportion to some *power* of the length (the displacement, for instance, being as the third, the moment of the plane of flotation as the fourth power, and so on of the rest), it follows, that if the lengths be placed in a certain ratio to each other, all the other elements will be in a certain, though different, ratio to each other; or, in other words, each element will form numbers in a geometrical progression. It has just been said, by way of illustration, that the displacement is as the third power of the length: were this precisely the case, tables could be dispensed with; but experience has pointed out that the displacement increases in rather a greater ratio. The like may be said of the other elements. It has therefore been the object, in the tables, to find out those proportions which experience has given, in ships of all sizes.

The first column gives the ships' names from whose elements (which are inserted in a different type) the table is formed; the second, the number of guns; the third, the weight of one round of shot, supposing the ship to carry all long guns,—a forty-two pounder carronade being reckoned as a twelve-pounder long gun, as it is nearly of the same weight; the thirty-two, twenty-four, and eighteen-pounder carronade, are estimated, for the same reason, as the nine, six, and four-pounder long gun, respectively. The next three columns show the proper size of the ship, to carry the weight of metal given in the second and third columns. It may be proper to observe here, that the quarter-deck, forecastle, and roundhouse, are accounted as fractional parts of a whole deck. The last column but one contains the proportion which the masts and yards of one ship bear to those of another. And the last column gives the moment of stability; that is, the weight of the ship, in tons, multiplied by the height of the metacentre, in feet, above the centre of gravity.

TABLE OF THE ELEMENTS OF SHIPS OF ALL CLASSES.

SHIPS' NAMES.	Number of Guns.	Weight of one Round of Shot.	Number of Decks.	Length at the Water-line	Breadth at the Water-line	Draught of Water in Midships.	Ports out of Water in Midships.	Moment of the Plane of Flotation, or $\int y^3 dx$	Displacement.	Square Root of Area of Sails.	Moment of Stability.
	No.	Lbs.	No.	Feet.	Feet.	Feet.	Feet.	Thousands	Tons.	Feet.	
	204	5600	5.9	243	64.8	30.0	5.7	6670	8400	196	37800
	192	5150	5.7	239	63.4	29.5	5.7	6190	7800	193	35600
	182	4760	5.4	234	62.1	29.0	5.8	5750	7280	190	33800
	172	4370	5.1	229	61.0	28.4	5.8	5320	6830	188	32200
	162	4030	4.9	224	59.5	27.9	5.8	4930	6400	185	30400
	153	3730	4.7	220	58.5	27.4	5.9	4580	6000	182	28800
	144	3430	4.5	216	57.5	26.8	5.9	4240	5600	180	27200
	137	3170	4.3	212	56.5	26.4	5.9	3920	5230	177	25800
	129	2920	4.1	208	55.5	26.0	6.0	3640	4900	175	24500
	122	2700	3.9	204	54.4	25.4	6.0	3370	4600	173	23200
Nelson.	122	2664	3.9	205	53.5	24.9	6.0	3335	4676	175	22196
	115	2500	3.72	200	53.5	25.0	6.0	3120	4400	170	22100
Caledonia.	122	2664	3.9	205	53.5	24.9	5.5	3155	4500	166	——
	109	2300	3.6	197	52.5	24.6	6.1	2900	4030	168	21000
	103	2110	3.4	193	51.5	24.1	6.1	2680	3780	166	20000
Boyne, as doubled	104	1958	3.9	186	52.3	23.3	4.9	2680	3980	160	——
	97	1950	3.3	190	50.5	23.6	6.1	2490	3530	164	19000
	92	1800	3.1	186	49.6	23.2	6.2	2300	3320	162	18000
	88	1660	3.0	183	48.6	22.8	6.2	2120	3110	160	17000
Colossus.	82	1628	2.9	180	48.9	21.9	5.8	2060	3000	161	15860
	82	1530	2.8	180	47.7	22.4	6.2	1970	2930	157	16100
St. Domingo.	82	1628	2.9	180	48.0	21.6	5.5	1960	2900	163	——
Ajax.	80	1604	2.9	176	47.5	22.1	5.8	1914	3000	157	17765

SHIPS' NAMES.	Number of Guns.	Weight of one Round of Shot.	Number of Decks.	Length at the Water-line	Breadth at the Water-line	Draught of Water in Midships.	Ports out of Water in Midships.	Moment of the Plane of Flotation, or $\int y^3 dx$	Displacement.	Square Root of Area of Sails.	Moment of Stability.
	No.	Lbs.	No.	Feet.	Feet.	Feet.	Feet.	Thousands	Tons.	Feet.	
	78	1410	2.7	176	46.9	22.0	6.3	1830	2730	155	15200
	74	1300	2.6	173	46.1	21.6	6.3	1700	2550	152	14400
	70	1200	2.5	170	45.3	21.2	6.4	1570	2400	150	13800
	66	1110	2.4	167	44.6	20.8	6.4	1450	2240	148	13100
	62	1020	2.2	164	43.4	20.4	6.5	1350	2080	146	12400
	59	940	2.1	161	42.9	20.0	6.5	1250	1960	144	11700
	56	870	2.0	158	42.0	19.6	6.6	1160	1830	142	11200
	53	800	1.9	155	41.3	19.3	6.6	1070	1720	140	10600
Endymion.	50	736	1.8	159	42.0	18.3	6.3	1111	1716	142	—
	50	735	1.9	152	40.6	19.0	6.6	990	1610	138	10100
	47	680	1.8	149	39.8	18.6	6.7	920	1510	136	9500
Revolutionaire.	46	666	1.8	157	39.9	17.6	7.8	940	1500	142	—
Leda.	46	666	1.8	150	40.0	18.4	6.7	881	1450	134	9521
	45	625	1.7	147	39.1	18.3	6.7	850	1410	135	9000
	42	575	1.6	144	38.3	18.0	6.7	790	1320	133	8600
	40	530	1.5	141	37.8	17.6	6.8	730	1240	131	8100
	38	490	1.5	139	37.0	17.3	6.8	680	1160	129	7750
	36	450	1.4	136	36.3	17.0	6.9	630	1090	127	7300
	34	415	1.3	134	35.7	16.8	6.9	580	1020	125	6900
	32	385	1.3	132	35.1	16.4	7.0	540	960	124	6550

From this class of vessels the ports decrease in height: this causes a different ratio to be adopted for the numbers in the geometrical series in the 4th, 8th, 10th, 11th, and 12th columns.

SHIPS' NAMES.	Number of Guns.	Weight of one Round of Shot.	Number of Decks.	Length at the Water-line	Breadth at the Water-line	Draught of Water in Midships.	Ports out of Water in Midships.	Moment of the Plane of Flotation, or $\int y^3 dx$	Displacement.	Square Root of Areas of Sails.	Moment of Stability.
	No.	Lbs.	No.	Feet.	Feet.	Feet.	Feet.	Thousands	Tons.	Feet.	
	30	356	1.2	129	34.5	16.1	6.9	500	900	123	6200
	28	330	1.2	127	34.0	15.8	6.8	460	844	121	5780
	27	302	1.2	124	33.3	15.5	6.6	426	798	118	5350
	26	280	1.2	122	32.7	15.2	6.4	400	742	116	5000
	24	260	1.2	120	32.1	14.9	6.2	370	696	114	4600
	23	240	1.2	118	31.5	14.6	6.0	340	650	112	4250
	22	220	1.2	116	31.0	14.3	5.8	315	610	110	3950
Bonne Citoyenne.	22	198	1.2	120	31.0	13.8	5.4	301	613	113	3917
	21	202	1.2	114	30.4	14.1	5.6	290	570	108	3670
	20	188	1.2	112	29.8	13.9	5.4	270	538	106	3380
	19	174	1.2	110	29.3	13.8	5.3	250	500	104	3130
	17	158	1.2	108	28.8	13.4	5.1	230	470	102	2900
	16	146	1.2	106	28.3	13.1	5.0	214	440	100	2680
Childers (brig).	18	156	1.2	100	30.5	13.1	4.8	217	450	97	2569
	15	136	1.2	104	27.8	12.9	4.8	197	410	98	2500
	15	125	1.1	102	27.3	12.7	4.7	182	385	96	2310
	14	116	1.1	100	26.8	12.4	4.5	169	360	94	2130
	13	106	1.1	99	26.4	12.2	4.4	156	338	92	1980
	12	99	1.1	97	25.8	11.9	4.2	146	315	90	1830
	12	91	1.1	95	25.3	11.7	4.1	134	295	89	1700
	11	83	1.1	93	24.9	11.5	4.0	123	280	87	1570
	10	77	1.1	92	24.4	11.3	3.8	114	260	85	1460
Rolla (brig).	10	60	1.1	90	24.5	11.1	4.2	114	277	82	1578
	10	71	1.1	90	24.0	11.1	3.7	106	245	84	1340

All the ratios between the numbers in the geometrical series, in the following classes of vessels, are increased by a multiple of 2.5.

SHIPS' NAMES.	Number of Guns.	Weight of one Round of Shot.	Number of Decks.	Length at the Water-line	Breadth at the Water-line	Draught of Water in Midships.	Ports out of Water in Midships.	Moment of the Plane of Flotation, or $\int y^3 dx$	Displacement.	Square Root of Area of Sails.	Moment of Stability.
	No.	Lbs.	No.	Feet.	Feet.	Feet.	Feet.	Thousands	Tons.	Feet.	
	9	58	1.1	86	23.0	10.6	3.4	87	206	80	1110
	8	48	1.1	83	22.1	10.1	3.2	72	176	76	920
	6	39	1.1	79	21.2	9.7	2.9	60	150	73	760
Sealark (schooner)	10	30	1.	77	21.9	10.0	3.7	57	166	76	737
	6	32	1.1	76	20.2	9.3	2.7	49	126	69	625
Flying Fish (sch.)	—	—	1.	77	20.3	8.3	2.8	44	117	73	—
	5	26	1.	72	19.3	8.8	2.5	40	108	66	520
	4	22	1.	69	18.4	8.5	2.3	32	91	63	430
	4	18	1.	66	17.6	8.1	2.1	27	78	60	350
	3	14	1.	63	16.8	7.7	2.0	23	66	57	290
Haddock (sch.)	4	12	1.	56	18.3	8.0	3.5	21	80	59	—
	3	12	1.	61	16.3	7.4	1.8	19	56	55	240
	3	10	1.	58	15.5	7.0	1.7	15	48	52	200
	2	8	1.	55	14 7	6.7	1.6	13	40	49	164
Rennie (cutter.)	—	—	1.	41.5	15.9	6.0	—	11	39	44	141
	2	7	1.	53	14.2	6.4	1.5	10	34	47	136
	2	6	1.	51	13.6	6.2	1.3	9	29	45	113
	1	5	1.	48	12.8	5.8	1.2	7	25	43	93
	1	4	.9	46	12.2	5.6	1.2	5.9	21	41	77
	1	3	.9	44	11.8	5.3	1.1	4 9	18	39	64
	1	3	.9	42	11.3	5.1	1.0	4.0	15	37	53
	1	2	.9	41	10.8	4.9	.9	3.3	12.8	35	44
	1	2	.9	39	10.4	4.6	.8	2.7	10.8	34	36
	1	1	.9	37	10.0	4.4	.8	2.2	9.2	32	30
	1	1	.9	36	9.6	4.2	.7	1.9	7.8	31	25
	1	1	.8	34	9.2	4.0	.7	1.5	6.6	29	20
	—	—	.8	33	8.8	3.9	.6	1.3	5.6	28	18
	—	—	.8	31	8.4	3.7	.6	1.0	4.8	27	14
Venus (pl. boat 12 tons.)	—	—	—	30.7	10.0	3.0	—	.98	5.6	30	—

The elements placed opposite the ships' names, are not included in the regular series of numbers: they are therefore distinguished, in the tables, by being printed in a different type. But it is necessary to remark, that the elements of all the ships were not made use of in the construction of the tables: those, principally, which have the column named "Moment of Stability" filled up, and a few of the others, were used; the remainder were added, for the sake of comparison, after the tabular numbers were completed.

It is a well-known fact, and easily accounted for on theoretic principles, that ships of a larger size are superior, in every respect, to those of smaller dimensions having the same number of decks, and carrying a proportional force. From the preceding table, ships of any size may be constructed, having all the properties of the best ships of each class which were in existence in the last war; but if we wish to improve our ships, we must, from what has just been observed, have tables of the elements of ships of larger dimensions than those already given. This could readily be done for all classes; but as both our three, and two-deckers are already so large, that it is difficult to procure spars to serve for their topmasts, it would be of little use to make tables for those classes: not so for the frigates, the largest of which, at present, only requires a seventy-four gun ship's masts and yards; a table is, therefore, added for them, formed for vessels of various sizes, from 208 to 1500 tons. This table is extended upwards, so that a frigate constructed from the elements in the first line could carry the same quantity of sail as the five-decker in the preceding table. The line marked (*a*) contains the elements of a frigate that would require a first-rate's masts and yards; those above that line must be considered as purely speculative, unless a different mode of masting is devised and adopted from that at present in use. The column for the number of decks is omitted, as inapplicable, in this table, and one for the tonnage is inserted in its place.

TABLE OF THE ELEMENTS OF FRIGATES.

SHIPS' NAMES.	Number of Guns.	Weight of one Round of Shot.	Length at the Water-line	Breadth at the Water-line	Builder's Tonnage.	Draught of Water in Midships.	Ports out of Water in Midships.	Moment of the Plane of Flotation, or $\int y^3 dx$	Displacement.	Square Root of Area of Sails.	Moment of Stability.
	No.	Lbs.	Feet.	Feet.	Tons.	Feet.	Feet.	Thousands	Tons.	Feet.	
	84	3210	205	54.0	2670	25.0	10.1	3510	3900	198	40100
	81	3000	201	53.0	2520	24.6	9.9	3250	3710	194	37000
	79	2760	197	52.0	2390	24.2	9.6	3020	3500	190	34100
	76	2520	194	51.8	2260	23.8	9.4	2780	3320	187	31400
	73	2310	191	51.0	2140	23.4	9.2	2590	3150	183	29100
	71	2100	188	50.3	2030	23.0	9.0	2400	2980	179	26800
	69	1910	184	49.4	1920	22.7	8.8	2220	2820	175	24700
(*a*)	66	1740	180	48.3	1820	22.3	8.6	2040	2670	171	22800
	64	1600	177	47.3	1730	22.0	8.5	1910	2520	168	21000
	62	1460	174	46.6	1650	21.6	8.3	1760	2400	164	19400
	60	1340	171	45.8	1560	21.2	8.2	1630	2270	160	17900
	58	1220	168	45.0	1475	20.8	8.0	1510	2140	157	16500
	56	1115	165	44.1	1400	20.4	7.8	1400	2030	155	15200
	54	1020	162	43.2	1330	20.1	7.7	1290	1920	152	14100
	52	930	159	42.5	1260	19.8	7.5	1210	1820	149	13000
	51	850	156	41.6	1187	19.5	7.4	1110	1725	146	12000
Endymion.	50	736	159	42.0	1238	18.3	6.3	1111	1716	147	
	49	780	154	40.9	1120	19.1	7.2	1030	1630	142	11200
	48	710	151	40.2	1070	18.8	7.0	950	1540	139	10900
	46	650	148	39.5	1020	18.5	6.9	882	1460	136	9400
Revolutionaire.	46	666	157	39.9	1145	17.6	7.8	940	1500	142	
Leda.	46	666	150	40.0	1062	18.4	6.7	881	1460	134	9521
	44	595	145	38.8	965	18.2	6.7	820	1380	133	8650
	43	545	143	38.0	915	18.0	6.6	760	1310	131	8000
	42	495	140	37.3	870	17.7	6.5	700	1240	128	7390
	40	455	138	36.6	820	17.4	6.4	650	1170	125	6800
	39	415	135	36.0	780	17.0	6.2	602	1110	123	6270
	38	378	133	35.4	740	16.8	6.1	560	1050	120	5780
	36	350	131	34.7	700	16.5	6.0	520	1000	118	5320

SHIPS' NAMES.	Number of Guns.	Weight of one Round of Shot.	Length at the Water-line	Breadth at the Water-line	Builder's Tonnage.	Draught of Water in Midships.	Ports out of Water in Midships.	Moment of the Plane of Flotation, or $\int y^3 dx$	Displacement.	Square Root of Area of Sails.	Moment of Stability.
	No	Lbs.	Feet.	Feet.	Tons.	Feet.	Feet.	Thousands	Tons.	Feet.	
Aquilon.	40	408	129	35·7	724	17.1	7·0	521	1084	125	—
	35	320	128	34.2	665	16.2	5·8	480	940	115	4920
	34	290	126	33.6	630	16.0	5·7	445	890	113	4530
	33	265	123	33.0	600	15.7	5·6	412	840	110	4190
	32	240	121	32·4	565	15.4	5·4	385	794	108	3850
	31	220	119	31·8	535	15.1	5·3	355	750	106	3560
	30	200	117	31·2	510	14.8	5·2	320	712	104	3290
	29	185	115	30·7	480	14.6	5·1	302	676	101	3030
	28	170	113	30·1	455	14.5	5·0	280	638	99	2800
	27	155	111	29·6	433	14.1	4·9	260	602	97	2580
	26	140	109	29·1	410	13.9	4·8	242	570	95	2370
Nautilus.	30	199	112	29·5	438	13.8	6·0	245	583	103	—
Rosamond.	26	170	108	29·5	422	13.8	5·0	238	589	96	—
	25	130	107	28·6	388	13.7	4·7	222	540	93	2200
Star.	26	188	106	28·0	365	14·2	4·3	218	595	96	—
	24	118	105	28.1	368	13.4	4·6	205	510	91	2020
	24	110	103	27·5	348	13.2	4·5	190	482	89	1870
	23	100	101	27·1	330	13.0	4·4	176	458	87	1720
	22	90	99	26·6	312	12·8	4·3	163	432	86	1580
Nautilus (old).	22	102	98	27·0	314	12.7	4·3	168	444	91	—
	21	82	98	26·1	295	12.6	4.2	151	410	84	1460
	21	75	96	25·6	280	12.4	4,1	140	386	82	1360
	20	68	94	25·1	265	12.2	4.0	128	366	80	1240
	19	63	92	24·6	250	12·0	3.9	119	346	78	1150
	19	58	91	24·2	237	11·8	3.9	110	328	77	1060
	18	52	89	23.8	224	11.5	3.8	102	310	75	980
	17	48	88	23.4	212	11.3	3.7	94	290	73	900
[1]Lynx (old).	16	41	87.6	23.2	208	9·4	4·0	95	248	82	—

[1] If this vessel had a quarter-deck and forecastle, it would cause an additional weight of 40 tons; making the displacement 288 tons, and diminishing the stability one-third,—which would reduce the square root of area of sails to 73.

The reader will perceive the almost perfect coincidence between the elements of the ships, and those of the table, in the line immediately above; and from that coincidence, and recollecting that the numbers in the column are in a geometrical progression, which connects the elements of all the ships, he will feel a confidence, in constructing from these numbers, superior to what can be derived from theoretic principles alone, until the science of naval architecture is much farther advanced.

The "Number of guns" in the second column may be varied according to circumstances, but very little alteration should take place in the weight of a round of shot. In placing the guns, the largest size should be on the lower gun-deck; the next size, in the usual progression, on the deck next above; and so on for the rest: but if, in large ships, the second tier is to be of the same weight and calibre as the lower tier, then the guns in the upper tiers must be proportionally smaller. The number of decks in the fourth column cannot be altered, (without corresponding alteration in the other elements,) but at the expense of a vessel's good properties. The length and breadth given in the tables are derived from the best ships; but if the vessel be made five feet longer and one foot narrower, or five feet shorter and one foot broader, she will retain, very nearly, the same good qualities, provided all the other elements be conformed to; indeed, in building small-sized ships, of the same number of decks, and of a proportionate force, as the common ones, the latter supposition should be adhered to: but such ships ought not to be built, it being better, in all respects, to have them of the class next below. The proportion of length to breadth, for brigs, should be as a hundred is to thirty; and, for cutters, as a hundred is to thirty-five. The numbers in the remaining columns, including those in the column headed "Number of Decks," will not admit of any alteration without injury to the qualities of the vessel.

Other columns might have been added to the tables, giving the minutiæ of naval construction; but as they are continually varying, and as it would have swelled considerably the size of the tables, they have been omitted. The rate of sailing would have been a very valuable element in the last table, if it could have been ascertained; but incomplete as the science of naval

architecture is, that of seamanship is incomparably more so: and the necessary result of this state of the science is, that the rate of sailing of a ship is so variously reported, at different times, that no accurate measure can be obtained, and we can only acquire the general notion already expressed in the preliminary remarks to the last table,—that the larger the ship, the better are her qualities. The area of the midship section, which, for an individual ship, is an essential element, because it prescribes the form, is, for that very reason, not inserted in the tables; it being deemed improper to trammel the fancy of the constructor on a subject the importance of which is not yet decided.

Useful tables could be constructed, on the same principle as the last, not only for the next inferior class of ships of war, which would contain corvettes and brigs, but also for steam-vessels, and yachts: these three classes, it is presumed, would include all that constructors would find serviceable. As for English merchant ships, tables of their elements would, at present, be entirely useless; for it would appear, they cannot be constructed amiss, provided they have a run, sufficiently clean, to admit of the action of the rudder. If they are full, they are capable of carrying a large cargo, and this gives them the character of good ships. If they are sharp, they can carry but a small cargo; but then they make their voyage in a shorter time: they are, therefore, thought to be good ships. If they are too narrow for their depth, their stability is made good by a greater quantity of ballast; and if they are too broad, they are made easy, in their rolling motion, by the omission of a portion of the ballast. That these representations of the low state of the mercantile shipping of this country, are not fanciful, any person may be convinced, who will take the trouble to examine the forms of any large collections of our merchant ships. Even if the only condition, mentioned above, is not attended to, and they are built so full abaft that the ship steers badly, (a case that frequently occurs,) the builders have a remedy in adding another stern-post abaft the one originally put in the ship; which, by bringing the rudder abaft the dead water, gives it sufficient influence in steering.

The calculations in the tables were made on the supposition

of the ships being built of the usual materials; but if it is intended to build a *fir* ship, a "Displacement" less than that given in the tables, is requisite; and if African oak is to be used in the structure, a greater displacement will be wanted. In general, it will be necessary to make calculations of the difference in the weight of every sort of material that varies from that of which ships are commonly built. This is a great labour, and sometimes must be encountered; but the method detailed in the following observations, will, for frigates, be found greatly to reduce that labour. Several 46-gun frigates have been built of red pine, of exactly the same form and dimensions, and timbers of the same size as the Leda, whose elements are given in the tables. The weight of a ship built of red pine, when launched, was 572 tons; that of the oak ship, the Leda, in similar circumstances, was 739 tons. The specific gravities of red pine and oak are, 950 and 657 respectively. Now, in order to find what part of the weight of each ship was in proportion to the specific gravity of the timber of which she was principally built, we must find out a weight that was *common* to *both* ships, on account of the decks, port-timbers, compass, or very crooked timbers, keel, and metallic fastenings, being of the same materials in both ships. If $w =$ the weight of the oak ship, $w' =$ the weight of the fir ship, $s =$ the specific gravity of oak, and $s' =$ the specific gravity of red pine, and $c =$ the weight common to both ships, we shall have $w - c : w' - c = s : s'$; from which we find $c = \frac{s\,w' - s'\,w}{s - s'} =$ 197, the weight, in tons, of the materials common to both ships: this leaves 542 and 375, for that part of the weight of the ships which is in the proportion of the specific gravities of the timber of which they were respectively built. If it were required to build such a ship of larch timber, instead of red pine, the above sum of 542 tons must be reduced, in the proportion of the specific gravities of oak and larch timber: that is, as 950 to 531. This gives 305, which, added to the common weight, 197, the sum is 502, for the launching weight of a 46-gun frigate built of larch timber: this is 237 tons less than the ship built of oak timber, and the total displacement ought to be so much less than that given in the table, for a ship of such a

size. As it is found that the weight of the hull bears a regular proportion to the whole displacement, in ships of all magnitudes, it will be easy, from the above numbers, to ascertain the weight of the hull of any sized frigates built of timber of any specific gravity, and thus to regulate the displacement accordingly.

That the "Height of the ports from the water in midships" is essential, as connected with the other elements, is made obvious from the following consideration:—That height determines the position of all the decks, with the guns, boats, topsides, anchors, men, &c.; and, if the quantity of sail be constant, it determines the length of the lower masts: all these things affect the centre of gravity, which, joined to an alteration in the height of the centre of effort of the sails, greatly influences the stability; and, consequently, the qualities of the ship are affected by it. It is not intended to assert, that the heights of the ports, given in the tables, are the best that can be adopted, but they are derived from the practice of all nations. Should it be thought to be an improvement to alter the height of the ports,—to raise them, for instance,—the influence it has in diminishing the stability, must be calculated; and, in order to counteract that influence, ballast must be added: this will increase the displacement, and, consequently, the resistance; to overcome which, more sail will be required; and, if the "Moment of the plane of flotation" be enlarged sufficiently, the ship will be enabled to carry it, and thus preserve all her good qualities.

The "Draught of water in midships," as it is stated in the tables, is necessary, if we intend to have the same weatherly properties as the ships from which they were derived: this draught of water must be maintained, whether the ships are long or short; for, though a long ship has a greater hold of the water, to keep her to windward, than a short ship, yet she has a proportional increase of topside exposed to the wind, to drive her to leeward.

As ships have always been built without their positive stabilities having first been ascertained, it may be thought that, to insert in the tables what is indicative of the same,—namely, their "Moment of stability,"—is only a matter of curiosity.

But, independently of the avoidance of the empirical mode, of making one ship the same comparative stability as another of the same size, it is really necessary, for a ship of an uncommon class, or for one that is greatly altered, to compare the force of the wind on the sails to the moment of stability, if we wish to escape the risk, and consequent disgrace, of a total failure. Another consideration, which is, indeed, of paramount importance, is, that, from the real stability of a ship, we may possibly arrive at the true theory of the resistance of fluids, or at least, by it, we can try the correctness of any theory that may be proposed, as it will certainly afford us the measure of the force of the wind on the sails, both transversely and longitudinally, by means of the angles of heeling, and of the depression of the bow.

The "Builder's tonnage" is inserted in the table, because, notwithstanding all the objections to it, it better characterizes the size of a ship (which alone should be understood by the term) than any other element. It also correctly determines the number of men proper to navigate the ship; for the two principal dimensions, the length and breadth, are equally involved in the builder's tonnage, and in masting the ship; and it is the magnitude of the sails (which depends on the masting), and not the quantity of the cargo, that limits the number of the crew. It is desirable that any future attempts to improve the mode of finding a ship's tonnage, may commence with a definition of that term: for, while some suppose the term to mean the *weight* a ship will carry, others suppose it to mean the *bulk* which the hold will contain; but the greater portion absurdly endeavour to combine these two things together.

As some of the readers of this work may be of opinion that the stability of a ship, as derived from the metacentre, is very erroneous, it becomes necessary, in order to prove the utility of that element in the tables, named the "Moment of the Plane of Flotation," to contrast that mode with the one demonstrated by Atwood to be correct. Some time since, a gentleman of great mathematical attainments, and who had been used to Atwood's mode of finding the stability of ships, together with the writer of the present article, undertook the Herculean task

of finding the exact centres of gravity, and from that the stability, by Atwood's method, of two frigates having the same elements, but of such dissimilar forms that one would have the greatest, and the other the least emersion and immersion, when inclined, that ships could possibly have. After proceeding a great way in the investigation of this problem, so interesting to naval architects, they were not allowed to finish their task; but enough had been done to state, that, at 12 degrees of inclination, the ship with the greatest immersion and emersion had $\frac{1}{28}$ more stability than the metacentric method would give, and the other ship $\frac{1}{18}$ less,—making, between the two, a difference of $\frac{1}{11}$. Now, as both ships must have the same total displacement, and as the above difference arises solely from the ship with the least calculated stability having a smaller portion of displacement near the water-line than the other, it follows that she must have a greater portion at some other place, which place will be near the keel. This will cause the ballast and all that is in her hold to be placed lower, which will lower the centre of gravity of the ship so much that it will diminish the difference above given almost to nothing. It thus appears, that the operose and retrograde method of Atwood, to find the stability ought to be superseded by the more elegant and easy method of Bouguer, by the metacentre.

From the tables, and more particularly from the principle, which has been explained, on which the last was constructed, improvements in every class of ships of war may be made to an extent limited only by nature, in the production of materials, and by the invention of man, in their application.

Art. VI.—*An Examination into the Form of Ships' Bodies, in connexion with the Passage of the Water, with a view to discover a Principle common to the Form of all fast-sailing Vessels:—by the Right Honourable* Lord Viscount Mandeville, M.P., *&c. &c. Communicated by* John Knowles, Esq., F.R.S.

The design of the following paper is, to endeavour to discover, in vessels built by persons who have only practical

knowledge, those principles which have been laid down by scientific men. It is not to be denied, but that small vessels, built by practical men, are often superior to those constructed upon scientific principles; and it is not surprising, that this has given occasion to ignorance to despise science, and say,—"There is no knowing what salt water likes." The writer hopes, that having no other view than the elucidation of truth, he may be thought free from violent prejudice, either on the one side or the other, and at least be useful by inducing others either to refute or confirm what he advances.

The characteristic features of vessels built by practical men are, great breadth, and a great rise in the floor. But it appears to have been the opinion of most mathematicians who have studied the science of naval architecture, that in order to reduce the plane of resistance, the breadth of the vessel ought to be diminished; and it becomes a matter of course, that a narrow vessel, in order to have the requisite displacement, must have a flat floor.

Figs. 15 and 16 represent the midship sections, or planes of resistance, of two vessels,—the one with a flat floor, the other with a great rise in the floor; and the part immersed of each, being composed of the same number of equal triangles, must of course be of equal surface. The question, then, in the first place, is,—which is the better adapted for stability? Now the one would have twenty, whereas the other would have upwards of twenty-seven, feet beam: so that the lever of support would be more than one-third longer in Fig. 16 than in Fig. 15; and, in addition to this, the ballast in Fig. 16 would act upon a lever longer in the same proportion.

Fig. 16 would not only have greater stability, but, when in motion, would not disturb the water so much as Fig. 15; that is, the curves in the direction in which the water would be divided, and in which it would close, are narrower in Fig. 16 than in Fig. 15; for the water will escape in the direction in which it finds least resistance, or, supposing the curves in other respects similar, in the direction of the narrowest curve. For the run of a vessel with a midship section formed like Fig. 16 may be tapered in the form of two wedges (Fig. 17): the one from the lower part of the bilge of the midship section, where

it is deep in the water but narrow, tapering to a vertical edge, —that is, the stern-post; the other from the upper part of the midship section, where it is broad but shallow, tapering horizontally to the counter: by which the angle of the taper of the stern would be diminished nearly one half, and the two currents of water will diverge, or, in other words, the water, in escaping from the upper half of the midship section, will resolve from the direction of the ribband-lines, or diagonals, to that of the buttock-lines, or perpendiculars; and from the lower half of the midship section, from the direction of the ribband-lines to that of the water-lines.

But the run of a vessel whose midship section is formed like Fig. 15, must be tapered almost entirely in one direction; that is, from the bilge to the counter: then the water from under the floor escapes upwards, in the direction of the buttock-lines; and the breadth of the curve it has to describe, is the whole depth of the bilge; and the water from the sides of the vessel escapes horizontally in the direction of the water-lines, which makes the breadth of the curve it describes, half the extreme breadth of the vessel, and the length only part of the length of the taper of the stern, when the two currents of water (the one from under the bottom, the other along the side,) must *converge*, and cause those eddies in the wake which always appear when a vessel of that form is going fast through the water. I think west-country-built vessels are, in this respect, not so faulty as those of the eastern coast; for, by sinking the counters lower, they decrease the curvature of the taper of the stern.

From what has been said, we may see the necessity, in flat-floored vessels, of limiting the breadth and depth as much as possible. But those vessels, not impelled by wind, or any power that requires a "hold in the water," may be advantageously built with a flat floor and shallow draught of water, as we see instanced in Deal rigs. And even sailing vessels may be so built, when their rig corresponds with their form, as is exemplified in luggers,—that being the rig with least gear and weight aloft; but then their unhandiness in working, caused by the great length required to spread the necessary quantity of canvas, limits the use of that form of vessel and rig to those situations and circumstances where they are enabled to "sail upon a stretch."

We may also see how mischievous is the English rule for measurement of tonnage; for, speaking in round numbers, supposing the breadth of one vessel to be one-fourth, and of another to be one-third of the length, each having the same capacity, and eighty feet in length, the one would measure 170, the other 310 tons.

It also follows, that the flatter the floor, the cleaner the run should be: and apparently from these sources, and partly on account of our mud harbours, we may trace the cause why English vessels, when built with a greater rise in the floor, with the intention of increasing their velocity, have not such handsome runs as those of America. For men who have been in the habit of building vessels with a flat floor, and who have consequently formed the run that the water may escape in the direction of the buttock-lines, having built only from experience, or "from the eye," as it is called, when altering the form of the midship section, still think it necessary to have "a clean run;" when, in fact, the water from below ought to escape more in the direction of the water-lines: and, if these be inflected curves, there is a great loss of power, without an adequate, if any, decrease of resistance. To give an instance of this:—A practical ship-builder, who saw the Royal George yacht, thought the fulness she had a little abaft the midship section, was "unfairness," and unintentional, and that she would not have been built of that form, had a model been first made, which might have been corrected by the eye. It is needless to add, how very superior she has proved.

As a vessel formed like Fig. 16 inclines, she presents an increased surface for support; and, the water pressing obliquely against a very much larger surface to leeward than to windward, tends to make her weatherly; which is the only way I can account for the saying, common in Bermuda, that their boats, which are built with a great rise in the floor, "fetch to windward of the place they look up for:" but this only holds good when the centre of gravity is low.

Having, as I conceive, proved that a form approaching to a triangle is much superior, for a midship section, to that of a square, I will now consider whether some modification of this principle might not be still better. If a portion were taken

from the lower part of the triangle, and added to the upper part, as represented by Fig. 16, the plane of resistance would still be the same size, but the strength of the form would be greater; as below there would be a convex surface *within*, to offer resistance to the weight of the ballast, and above there would be a convex surface to offer resistance to the pressure of water from *without*.

This form would decrease the lee-way, for the water would not escape so readily along an inflected surface.

But the principal advantage would be, that, in inclining, the ship would roll more easily, and the emersion and immersion would be more equalized; but this ought, as before observed, to be governed by the position of the centre of gravity. When the centre of gravity is at the water's edge, emersion and immersion should be equal; consequently, the breadth ought to be the same for 15 degrees above and below the load-water-line, supposing that to be the greatest angle of inclination; else, were the immersion greater than the emersion, the vessel being buoyed up, would become less weatherly.

The effect of the change of position of the centre of gravity may be instanced by the fact of many *previously* fast-sailing vessels, sailing ill when brought into His Majesty's service, and undergoing the alterations and additions of guns, booms, bulwarks, and other heavy upper works, by which the centre of gravity is raised. That being the case, if they in any great degree fall in below, and fall out above the load-water-line, it is evident that, in inclining, the vessel must become leewardly. But when the centre of gravity was low, the vessel's stability proceeded from the ballast acting upon a lever, the length of which was from the centre of gravity to the extreme breadth of the part immersed to leeward.

Immediately at the surface, the water, in the centre of the vessel, must run nearly in the direction of the water-line: this may be a slight additional reason why the timbers at the load-water-line ought to be perpendicular to the surface of the water; but the water does not run horizontally,—either at the bow, as there a wave is formed, or at the stern, as there another wave is formed; and the cleaner the run is below, or the more suddenly it is formed, so the fuller should be the water-

line abaft: for, as the vessel moves ahead, the water will run in from all directions to fill up the vacuum, and will sink more or less at the counter, according to the space to be filled up.

I will now consider the *form* of the curves, or lines, in the direction in which the water is divided, and in which it closes. By many vessels of perfectly different forms sailing nearly equally well, apparently the only thing conceived necessary by practical men, is, that the lines should be "fair curves," without any one particular curve being supposed better than another. The fact may partly arise from the increasing ratios of resistance to velocity, but partly also from the water escaping in the direction in which it meets with least resistance. So that, whatever may be the form of the vessel, the lines in the direction in which the water is divided and closes, may not be so very different; though practice seems universally opposed to the conclusions drawn from the experiments tried in the years 1796 and 1798: viz., "that a long parallel body, terminating at each end in a parabolic cuneus, is the form best adapted for velocity."

Most of the fast-sailing vessels, such as the smuggling vessels on our coasts, are built "by the eye:" that is, a midship frame is put up; then the planking is put on, and only forced out a little at the bow; the timbers are put in afterwards. Thus the form of the lines must be the natural curve of the plank, or nearly so; and by clinker-built vessels sailing quite as fast as carvel-built, it appears evident that (excepting immediately at the surface) water is displaced and closes in the direction of the planks; otherwise, the resistance would be great at the edge of every plank, or "land," as it is called.[1] Now this curve, in these vessels, must be nearly a catenary, which I therefore think is probably the best. I speak with great diffidence, but it appears to me that the curve a chain would take, with an equal weight in every part, would offer equal resistance in every part.

There seems to be a peculiar adaptation to circumstances in the catenary; for if, in order to obtain the curve of least resistance for a different rate of velocity, one of the points of suspension be made more or less horizontal, all the required altera-

[1] I am indebted to Mr. Wilson, of the Navy Office, for this observation.

tion takes place. For instance: for a velocity not exceeding five miles in the hour, let the two points of suspension be horizontal; then the extreme breadth will be in the centre, and the bow and stern will be equally acute. But to get a curve of least resistance for a higher velocity, one of the points of suspension must be elevated, when, at once, all the alteration takes place: that is, the breadth is removed farther forward, the bow becomes more full, and the length of the taper of the stern is increased; while, at the same time, the proportion of the fore and after bodies is, in a certain degree, preserved. Here I cannot help remarking the absurdity of the common observation, "that the form of a fish is the best model to copy:" for, taking the argument on which this is founded, that nature, or, rather, infinite wisdom, best adapts every thing for the purpose for which it is intended, and that fish must be so formed as to move with the greatest ease in their own element, it is evident their form must be suited to their velocity, which is far beyond that of the fastest vessels; and thus we see, in the dolphin, (which I take, supposing it to be the fleetest fish,) the extreme breadth is farthest forward,—I should conceive not one twelfth of the length from forward; and the taper of the stern is also of course very long. This observation only relates to the proportions of the curve; not touching another great discrepancy,—namely, the fish being wholly immersed in the fluid,—there might be also another reason: the increased propelling power in the greater length of the tail. This brings me to the next consideration, namely, the situation of the extreme breadth:—On account of the position of the centre of gravity, I should conceive the extreme breadth ought to be very nearly amidships. I would agree with Chapman, or the French, "from one-twentieth to one-twelfth of the length" before the centre of the vessel: but there is a greater consideration, namely, the probable average velocity, in connexion with the necessary breadth; by which I mean, that the situation of the extreme breadth is not of so much consequence as the angle of the taper of the stern. In high velocities, there is a long vacuum which a taper stern might fill up, without increasing the resistance, though with a great increase of *vis instita*; whereas, in less velocities, it would be more advantageous to

diminish the *head*-resistance, by making the angle of the bow more acute. A London wherry is a practical exemplification: in it, the extreme breadth at the gunwale is very far aft. Now, when light, and without sitters, and she is able to attain nearly the velocity of five miles in the hour, the extreme breadth of the water-line is amidships; but as all increased weight is put abaft the centre, when she is heavily laden, and only able to attain half that velocity, the extreme breadth of the then water-line is removed far aft, though she would be still nearly on an even keel. From the experiments made by the Society for the Improvement of Naval Architecture, it would seem necessary that the length of the taper of the stern be three times the breadth; and this point, I think, for any vessel whose velocity is intended to exceed five miles in the hour, ought first to be attained: after that is secured, the nearer the extreme breadth is to the centre of the vessel, the better.

With respect to the bow, a short ship cannot bear so sharp a bow as a long one can; but a full bow will make a vessel carry great weather helm. In the experiments of the French Academy, on the resistance of bows of different angles, from 180° to 12°, varying 12° in each experiment, the greatest difference of resistance was between 96° and 12°, more or less, and the difference between each of the others decreased in a very great ratio; which inclines me to believe, that somewhere about sixty degrees is sufficiently acute for the lower velocities, and in the higher velocities the bow ought to be as full as eighty degrees, as the water, in impinging, flies off, and thus you procure increased *vis instita*, without proportionably increased resistance: so that the bow may vary between sixty and eighty degrees, according to circumstances; and this will embrace the variety that there is among fast-sailing vessels.

Perhaps the same cause that prevented the runs of English vessels from being of the best form, might have necessitated our architects to study more closely the form of the fore body; and I think our bows are superior to those of America. And in this the vessels of the south-east coast have the advantage of those of the west coast.

The concavity in the bow-timbers, which English vessels generally have, but which Americans carefully avoid, gives

more support in pitching. By referring to Fig. 18, where, in the two bows $a\,a'$ and $b\,b'$, the capacity is equal, the capacity for support in pitching is greater in the one than in the other, by the distance from a to b. But let us refer to what was before mentioned, with respect to the run; namely, the water escaping in the direction of the planks: and these planks being parallel to the surface of the timbers, a line drawn at right angles to the timbers will describe their direction, as $c\,e$, $c'\,e'$, $c\,d$, $c'\,d'$. But here the object to be attained is exactly the reverse of what it was in the former case: the run is formed so as to *induce* the water to escape *from* the midship section, in that direction which would make the angles of delivery the most acute possible; but now the object is to induce the water to go from each part of the stem to that part of the midship section which will form the curve of least breadth.

But though the form must be described by lines, our views will be more correct by bearing in mind, that that which is to be overcome is the resistance of a *film* of water, lapsing from the direction in which it is first divided (namely, vertically by the stem) to the diagonal direction at the midship section, where it begins to close. And this will be attained, by gradually altering the rise of the bow-timbers from the angle of the floor to the vertical direction of the stem. And it also appears, that the best mould for all the bow-timbers below what will be the surface of the water when the vessel is in motion, will be nearly the form of that part of the midship section which is below the water, the curve of each timber being gradually less inflected; but if the hollow be made more concave, or the swell more convex, the water will be disturbed more than is necessary.

From what has been said, it appears that every thing depends upon the midship section: not that the extremes are not of consequence, but that the form of the extremes must, in a great measure, depend upon that section. We may also notice, that the extreme breadth of the curves depends, not upon the extreme breadth of the vessel, but upon that diagonal line which divides the two wedges by which the run is formed; and this line I consider the *master-line*.

I have sometimes thought, that there is a double resistance

to be considered: the one in the direction in which the water glides along the surface of the vessel, the other in the direction of the vessel's course; and, with respect to this latter, the form of the water-lines must be considered, and upon them would much depend the weatherly properties of the vessel. This may account for a straightness, and sometimes even an abruptness, in the water-lines of the bow, which, when the vessel is inclined, gives great weatherly properties. A ship's carrying weather-helm is considered indicative of her being weatherly, and I think justly: for the same cause, namely, the water pressing obliquely against a large surface to leeward, produces the two effects.

Too great *ardency* can be, and indeed is, in all small fast-sailing vessels, counteracted by the vessel's having a greater draught of water aft than forward; and in this there is another advantage: when sailing on a wind, a vessel is able to carry more after-sail, and the carrying less head-sail in proportion will greatly ease her in pitching. I remember the draught of water of the fastest sailing boat at Bermuda, was 2 feet 6 inches forward, and upwards of 7 feet abaft, she being only eight-and-twenty feet long; but then they have an extremely small jib, and a very large mainsail, with a long boom over the stern.

Vessels built by practical men have the after part above water, or the counters very full,—I suppose in order that the axis of inclination may be parallel to a line drawn from the stem to the stern-post, and also to the water-lines; for, when going a-head, on a wind, there is a greater support required for the counter than for the bow: for "[1]the water no longer presses equally in all directions, having a greater tendency to escape in the direction of its motion than in any other; the vertical pressure is less, therefore, on the surface of the after body than when at rest." As we may see, in vessels hanging to buoys in tide-ways, the counters always sink and bows rise; but when lying at anchor, the direction of the cable depresses the bow; and when going before the wind, the sail depresses it.

One of the objections to this form of building is, the supposed increased expense: this, of course, is the case, if a vessel is

[1] Art. XVI., vol. i., Papers on Naval Architecture.

built for so much a ton, and the tonnage is measured by the common calculation. But I think it ought to be exactly the reverse; for it is only adopting in the *form*, the principle of Sir Robert Seppings's beautiful *mode* of construction:—"that a triangle is as unalterable as the compression or extension of the fibre of the timber will admit it to be; whereas a square, with the least pressure, may be made to change its form to a rhombus:"—from which I infer that equal strength may be attained, with much less timber, in the one form than in the other. And in addition to this, there cannot be so great a tendency to hogging, as the support along the whole length of the vessel will be more equalized; and this brings me to my last observation: but what I am now about to say, I can hardly call the custom of practical men generally; for, indeed, I know not above one or two instances. It is, giving a curvature to the rabbet of the keel; but such that a vessel should, in no place, draw more water than she otherwise would draw abaft, by which the stability would be increased, in consequence of the ballast being brought so much lower; it would also greatly prevent the tendency to hogging. The principle is that of Mr. Greathead's life boats, which appears to have been suggested to the inventor by the following simple fact: "Take a spheroid, and divide it into quarters; each quarter is elliptical, and nearly resembling the half of a wooden bowl, having a curvature with projecting ends. This, being thrown into the sea, cannot be upset, or lie with the bottom upwards." This boat has answered, and even exceeded every expectation: the curvature of the keel and bottom facilitates her movement in turning, the boat moving as it were upon a centre. The concavity of the bottom, and the elliptical form of the stem, admit her to rise with wonderful buoyancy in a high sea, and so launch forward with rapidity.

Hutchinson also proposes this, and mentions, in support of it, "a vessel that was much improved by her bottom having been bent down by a heavy cargo being put in her centre." I will also mention the Pearl yacht, than which there are few, if any, vessels better: she also has a slight curvature in the rabbet of the keel.

In recapitulation, I would observe, the triangular midship

section, concave bow-timbers, and the run formed for the water to escape in the two directions, have not only *each* the positive advantage of increasing the stability, by increasing the area of the load-water-line, (or, stating it otherwise, decreasing the plane of resistance of a vessel of equal stability,) but also of diminishing the resistance, by contracting the breadth of the curves, and reducing the angles in the direction in which the water passes: indeed, it appears to me the only way in which the angle of the taper of the stern of a sailing vessel can be reduced to the desired acuteness of eighteen degrees, the angle of the bow being from sixty to eighty degrees. The plane of lateral resistance would be greatly increased, both by the triangular midship section, as well as by the curvature of the keel, which would of course increase the weatherly properties.

But, after all, the direction the water will take must be that of lines of double curvature, which would be almost impossible to be described or laid down on paper; so that still much will remain dependent on experience, or "the eye," or "fairness" of form, or what is described by some other such expression, which must be vague and uncertain. It is proper to add, that these observations refer to small vessels built solely for velocity. The Figures are merely such as will best illustrate the argument, and not at all as being any form proposed for a ship.

Art. VII.—*A Method for finding the weight of a Ship, without knowing its Magnitude or Form. By* William Walker, Esq., *Assistant Master Attendant of His Majesty's Dockyard at Devonport.*

To the Editor of Papers on Naval Architecture.

The following method for finding the actual weight of floating bodies, suggested itself to me, by observing that a 78-gun ship floated deeper in the river Medway, at low water, than at high tide; and I am induced to publish it, because some of your readers may have conceived it impossible to find the weight of a ship without knowing her form, magnitude,

and displacement. I am, however, of opinion, that the following is the only true method by which the actual weight of a ship can be ascertained: it is by this, weighed as by the hydrostatic balance.

Ex. 1. A ship at London had her water-line marked very exactly, and a certain quantity of the Thames water weighed 1000 lbs.: on the ship arriving at Sheerness, it required 25 tons additional weight, to bring her down to her water-line marked at London; a quantity of the water in which she floated, equal to that weighed at London, was found to weigh 1026 lbs.; required the weight of the ship in air when she left London?

Floating bodies displace a quantity of fluid, equal in weight to themselves. By this principle, the displacement at London and Sheerness, although different in quantity, was equal in weight to the ship; therefore the difference of displacement, in the two fluids, bore a certain ratio to the whole: this difference was equal to 25 tons. It was also found, that a certain quantity of the river water weighed 1000 lbs., and an equal quantity of sea water 1026 lbs.; therefore their difference, 26 lbs., will be to 1000 lbs. as 25 tons to the weight of the ship in the atmosphere. As 26 lbs. : 1000 lbs. :: 25 tons = 961 tons 10 cwt. 3 qrs. $2\frac{4}{26}$ lbs.

Ex. 2. The line of flotation of a yacht was carefully marked in salt water, a certain quantity of which was found to weigh 103 lbs. imperial; the vessel was then moved into a river, and seven tons ten hundred weight was taken out of her, to bring her to the line of flotation marked at sea. A quantity of the river water, equal to the salt water weighed before, was found to weigh 100 lbs.; required the weight of the yacht in the atmosphere, and her displacement, in cubic feet, at sea, supposing a cubic foot of sea water equal to 64 lbs.?

	Lbs.		Tons. Cwt.		Tons.
As	3 : 100	::	7 10	=	250, the weight of the vessel when in the river.
As	3 : 103	::	7 10	=	$257\frac{1}{2}$, the weight of the vessel when at sea.

As 64 : 1 :: $257\frac{1}{2} = 9012\frac{1}{2}$, cubic feet displaced.

Ex. 3. A collier's water-line was carefully marked at sea, and a quantity of sea water was found to weigh 51 lbs. 8 oz. On her arrival at London, 20 tons of coals were taken out to bring her to her former water-line; and a quantity of the Thames water, equal to that weighed at sea, was found to be 50 lbs.; required the weight of the vessel and stores, supposing her cargo, when complete, to have been three hundred tons?

	Lbs.		Tons.		Tons.	Cwt.	Qrs.	Lbs.	
As	1.5 :	50 ::	20	=	666	13	1	$9\frac{1}{3}$	in the river.
As	1.5 :	515 ::	20	=	686	13	1	$9\frac{1}{3}$	at sea.
		Deduct cargo			300	0	0	0	
					386	13	1	$9\frac{1}{3}$,	weight of the vessel and stores.

Let the following query be answered by some of your correspondents:—

Will the above calculations be affected by the temperature of the air or water? If so, in what ratio, giving the reason for such opinion.

WILLIAM WALKER, R.N.

Devonport, Nov. 20th, 1827.

ART. VIII.—*Observations on the Dimensions and Properties of Ships of various Classes in the British Navy, with an Application of the Subject to the Ships of the late experimental Squadron, under the Command of Rear-Admiral Sir Thomas Hardy, Bart., K.C.B., &c. By* MR. BENNETT.

THE consideration of the dimensions of ships, is a most important subject, both as it regards their sailing qualities, and the expense of their construction. It is reasonable to suppose, that there must be some certain ratio between the length and breadth of ships, which is to be preferred to others, and which, at the same time, is not equally applicable to all classes; yet it is to be feared, that this is but very imperfectly understood, or, if understood, is too often overlooked. Almost every modifi-

cation of form has been given to vessels, but, whilst we have refined on minutiæ, we have neglected generalities;—we have commenced our labours where they should terminate: the most eligible principal dimensions of ships should be first established, before we pay an exclusive attention to minor considerations.

The absolute length of a ship is, or ought to be, a determinate quantity. In designing a ship, we first decide on the number and nature of the guns she is to carry; next, on the size of the ports, and on the intervals between them, required for working the guns; as also on the distance between the foremost port and the stem, and the aftermost port and the sternpost: from the sum of these distances, we obtain the length of the ship. After an ample space for fighting the guns, &c., has been once decided on by competent judges, any deviation from this decision should be regarded as an error in judgment. If the length be increased beyond these limits, an unnecessary expense is thereby incurred.

Again, the number and weight of the guns determine the number of the crew; the number of the crew decides the quantity of provisions and water required for their sustenance during a certain time, which, to a considerable extent, denotes the capacity of the hull necessary for stowage: so that it appears that on the *armament* of a ship of war depend three very essential elements; viz., her length, her capacity, and the number of her crew.

Supposing that we have now fixed on the lengths of ships of various classes, we are next to determine on their most advantageous breadth, which will involve far more difficult considerations than the preceding. One of our first inquiries would be, whether all ships should have the same proportion between their length and breadth; or whether the relative breadth of the least ship should be greater or less than that of the greatest ship. Some persons would naturally refer to experience to decide on a question so obviously important; others would form their judgment from scientific reasonings, combined with general facts. We will first see what information can be gained from experience, by analyzing the ratio of the length to the breadth of our navy, selecting a sufficient number of ships from each class, to form a general opinion on the subject. Cutters,

schooners, &c., from their peculiar construction, may be neglected in this inquiry. Other vessels than those at present in the service will be occasionally introduced, as they may serve to elucidate the subject.

The three-decked ships of 120 guns, as the Caledonia, Britannia, Prince Regent, Howe, Nelson, and St. Vincent, have the same ratio of length[1] to breadth, being 3. 83 times as long as they are broad. Our smaller first-rates have less relative length than the above ships. The San Josef was 3. 58 times, and the Salvador del Mundo was 3. 50 times as long, as she was broad. The old St. George had greater relative breadth than these, being only 3. 42 times as long as broad. There is little agreement between the relative dimensions of the remainder of our three-deckers. The ratio of the length to the breadth of the Queen Charlotte, and Royal George, is as 3. 61 to 1; that of the Hibernia, Ville de Paris, and Royal Sovereign, is respectively as 3. 78, 3. 57, and 3. 52 to 1.

The second-rate three-decked ships, similar to the Victory, as the Boyne and Union, are 3. 62 times as long as they are broad; as are also the Dreadnought, the old Neptune, the Prince of Wales, and the Temeraire; the Barfleur and Prince George were 3. 52 times as long as they were broad. The Impregnable has the same ratio of length to breadth as the Caledonia, namely, 3. 83 to 1. The Prince is among the longest ships in the service, being 3. 96, or nearly 4 times as long as she is broad.

The large two-deckers of 84 guns, built after the French Canopus, as the Formidable, Ganges, Monarch, &c., are 3. 78 times as long as they are broad. The Malta, Marengo, Pompée, Spartiate, Tonnant, and Impeteux, which were captured from the French, had nearly the same proportion of length to breadth as the Canopus class; the difference is too inconsiderable to deserve notice. The Gibraltar, of 82 guns, taken from the Spaniards, was only 3. 35 times as long as she

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[1] In this comparison, the lengths of the line of battle ships are taken on the gun-decks; the lengths of the frigates on the lower deck. Could the lengths have been obtained at the load-water section, it would have been preferred; the error, however, arising from this circumstance will not be considerable.

was broad. The Christian VII., captured from the Danes, together with the Cambridge, built after her, was 3.67 times as long as she was broad. The San Nicolas (taken from the Spaniards), the Waldemaar (taken from the Danes), the Foudroyant, and the Canada, had a ratio of length to breadth, of about 3.62 to 1.

The Surveyor's class of seventy-fours, as the Armada, Agincourt, Barham, Rodney, and many others, are 3.7 times as long as they are broad. The Bellerophon, Elephant, Excellent, Vanguard, &c., built after the old Arrogant, are 3.58 times as long as they are broad; as were also the Hector and Montague, which were similar to the old Royal Oak. The Bulwark and the Rochfort are respectively 3.69 and 3.90 times as long as they are broad.

The general proportion of length to breadth, of the smaller class of ships of two decks, which carried 64 guns, varied between the limits of 3.52 and 3.59 to 1: among these, we may notice the Africa, Europe, Leyden, Stately, and St. Albans. The Centurion, Antelope, Grampus, and Jupiter, which carried 58 guns, were respectively 3.61, 3.65, 3.68, and 3.70 times as long as they were broad. Several ships in this class may be mentioned, which possess a very great relative length; but, as they were originally merchant vessels taken into the service through necessity, we cannot with propriety include them when forming an estimate of the ratio of the length to the breadth, of the navy generally. Among these may be noticed the Coromandel, which ship is remarkable for her excess of length, being 4.53 times as long as she is broad; also the Ardent, Argonaut, and the old Lancaster, which were four times as long as they were broad. The Glatton and Bristol had rather less relative length than the above ships, the former being 3.89 times, and the latter 3.98 times, as long as she was broad.

In referring to the dimensions of our frigates, we find the largest class of 60 guns, as the Southampton, Winchester, Portland, &c., have their length to their breadth in the proportion of 3.93 to 1. These ships, as a distinct class, are the longest in our navy; although we have ships which are equally long, as the Blanche and Fisgard, captured from the French, and the Rochfort and Newcastle, designed by M.

Barallier; but as we do not build after these ships, neither of them can be said to constitute a separate class. The President, built after the American frigate of the same name, has rather less relative length than the Southampton, Winchester, &c., being 3.90 times as long as she is broad. The numerous class of ships of 46 guns, constructed after the old Leda, as the Blanche, Fox, Penelope, Thalia, &c. &c., have their length to their breadth in the ratio of 3.76 to 1; the Liffey, Liverpool, and Glasgow, built after the Endymion, are similarly proportioned. The Apollo, Laurel, Nymphe, Undaunted, with many others built after the old Lively, are 3.89 times as long as they are broad. It will be needless to extend these remarks on the dimensions of frigates of these classes, except by observing, that between the relative dimensions of the Imperieuse and Phaeton, which are 3.60 times as long as they are broad, and those of our large frigates, which are 3.93 times as long as they are broad, we may find every variety of length and breadth.

The small frigates of 28 guns, built after the old Enterprise, as the Dido, Lapwing, Alligator, &c., were 3.58 times as long as they were broad. This class is now substituted by the Niemen, Athol, Ranger, &c., which have their length to their breadth as 3.60 to 1. The frigates of 24 guns similar to the Amphitrite, as the Eurydice and old Champion, were 3.55 times as long as they were broad. Those of 26 guns, built after the old French Amazon, with those built after the old Pluto, were about 3.65 times as long as they were broad. We may here observe the difference of opinion between the English and French, respecting the relative dimensions of small frigates. The Tourterelle, which was captured from them in the year 1795, was 3.97 times as long as she was broad; the Jamaica, which was captured in the succeeding year, was 3.91 times as long as she was broad. The Astrée, Valeureuse, and Fortunée,[1] were respectively 3.83, 3.97, and 3.80 times as long as they were broad. The relative length of all these ships considerably exceeds that which we have hitherto given to small frigates; and becomes interesting, inasmuch as it will be here-

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[1] **Farther particulars concerning these vessels, are given in page 403, Vol. I., of Papers on Naval Architecture.**

after seen, that two of the frigates of the experimental squadron have the same proportion of length to breadth as one of the above-named French ships.

A great number of our corvettes were built similar to the Bonne Citoyenne, as the Bann, Cyrus, Myrmidon, &c.; the ratio of their length to their breadth was as 3.87 to 1. Some were constructed after the Indian, as the Sylph, Morgiana, &c.; these were 3.58 times as long as they were broad. Others after the old Merlin, as the Ariel, Albacore, Otter, &c., which were 3.77 times as long as they were broad. The Martin and Rose are respectively 3.75 and 3.53 times as long as they are broad.

On examining the dimensions of our brigs, we shall perceive the same diversity among them as among the other classes of the navy; for whilst those built after the Cruizer, as the Sparrowhawk, Trinculo, Alert, &c., have their length to their breadth in the proportion of 3.27 to 1; the ratio of the length to the breadth of the Manly, Hasty, Mastiff, &c., is as 3.80 to 1.

From this inquiry may be deduced the most unexpected anomalies, as every variety of relative length and breadth exists, not only in the various classes of ships, but even in ships of the same class; among which, at least, we might have anticipated a uniformity. We find instances, among brigs, corvettes, frigates, and two-decked ships, of some having equal, others greater, and several less relative length than ships of 120 guns. Although by the experience of ages, the dimensions of ships have not hitherto been determined, yet we conceive, that by a scientific use of this experience, such knowledge might be obtained, as would enable a constructor to decide on the relative dimensions of all classes of ships, agreeably to their magnitude and service; and, at the least, the object may be advanced by the attempt.

We, however, find difficulties in the very commencement of the inquiry,—difficulties which it would be almost impossible for the exertion of one individual fully to overcome. So little is known concerning the ships composing our navy, that we cannot say to what extent additional decks and guns diminish the stability, or to what extent a general augmentation of the size of ships increases the stability. It is true, that with

great labour and industry, the centres of gravity of one or two large ships have been calculated; and by assuming the centre of gravity of smaller ships to be near the water, which will not be very far from the truth, we may (from the result of calculations on the stability of these ships) conclude that the moment of stability of ships increases in a greater proportion than their capacities. This, indeed, might be inferred, from considering, that the capacities of ships increase as the cubes of their dimensions, whereas the stability increases as the fourth power of their dimensions. The inference to be drawn from this is, that small ships should have greater relative breadth than large ships: this, however, must be understood with certain limitations; it may be a general, but not an universal truth. Were all ships homogeneous,—thus if a navy consisted entirely of corvettes, the corvette of 18 guns ought to be relatively broader than the corvette of 120 guns; this is a rule without any exception. It may be farther observed, from the previous remarks, that the corvette of 18 guns should be relatively broader than the three-decked ship of 120 guns; but if a ship were built to carry 120 guns on four, or even on five decks, her relative breadth should then approximate to, and should most likely exceed, that of the corvette, in order to ensure sufficient stability. The consideration of this simple case, may tend to elucidate the principles of stability, when applied to cases of greater difficulty. If a three-decked ship of 120 guns is to carry the same force, on a greater number of decks, her absolute length would of course be reduced; and supposing her breadth to remain the same, the positive part of the expression for stability would be thereby diminished. The displacement, which is one element of the negative part of the expression, would probably remain nearly the same, as the additional weight of topside might counterbalance the reduction of weight occasioned by less length. If the displacement be equal in each case, the draught of water would be increased, from the diminution of length; this would lower the centre of gravity of displacement, which, together with the centre of gravity of the ship being raised by the additional weight above the water, would increase the distance between the centre of gravity of the ship and that of the displacement. On the whole, there-

fore, the positive part of the expression would be diminished, and the negative part increased; so that the stability would be less in a ship of the same force and breadth as another ship, but which carried her guns on a greater number of decks.

Having seen the necessity, in the case of a ship carrying the same number and weight of guns as another ship, but on more decks, of increasing the breadth, in order to avoid a deficiency of stability; we may evidently trace the same principle existing between the *largest* ship of an inferior class, and the *least* ship of a superior class, in which, if the number of guns be not equal, it approximates sufficiently to make the application apparent; so that, in the several gradations of corvettes, frigates, two-decked ships, and three-decked ships, *the least vessel of each class* is liable to be wanting in stability, from its small comparative dimensions not sufficiently counteracting the effect of additional decks and guns. In this case, therefore, above all others, particular care should be taken to give sufficient breadth to compensate for a tendency to deficiency in stability; so that, without much liability to error, we may conclude,—

1st, That the small frigate should be relatively broader than the large corvette.

2d, That the small two-decker should be relatively broader than the large frigate.

3d, That the small three-decker should be relatively broader than the large two-decker.

Between each of these varieties there will be a certain point, (if the expression may be used,) where the superior and inferior classes of ships should have the same ratio of length to breadth: this arises from the enlargement of their dimensions increasing the stability in a greater proportion than the weight of additional decks and guns diminishes the stability. Thus,

4th, The middling-sized frigate should have the same ratio of length to breadth as the large corvette.

5th, The middling-sized two-decker should have the same ratio of length to breadth as the large frigate.

6th, The middling-sized three-decker should have the same ratio of length to breadth as the large two-decker.

As corollaries from the first three observations, we may remark,

7th, That the large corvette should be relatively broader than the large frigate.

8th, That the large frigate should be relatively broader than the large two-decker.

9th, That the large two-decker should be relatively broader than the large three-decker.

Hence the largest ship of each respective class should be the longest; and there appears to be no general rule, whether large ships or small ships, should have the greater relative breadth, as the ratio between the length and breadth depends as much on the manner of carrying the guns as on the magnitude of the ships; moreover, that notwithstanding the above apparent ambiguity, this inquiry resolves itself into the simple proposition,—having given the armament of a ship, with the number of her decks, to find the ratio between her length and breadth; which is always reducible to one of the nine before-mentioned cases; that is, supposing we have one ship,—for instance, a corvette,—which may be taken as a standard, from experience proving the propriety of her dimensions. If any principle be here established, it is only in kind, not in degree: thus, when the ninth observation implies that the large two-decker should be relatively broader than the large three-decker, we do not pretend to assert the exact quantity which her breadth should exceed that of the three-decker. An approximation to accuracy is, however, better than absolute error; and if with our present imperfect knowledge of the properties and elements of our ships, we may place any dependance on the nine cases here laid down, may we not reasonably anticipate far greater advantages from an elaborate and scientific analysis of our navy generally?

It would have been an interesting, and perhaps an instructive occupation, to have examined how far the above nine conditions agree with experience; but these remarks are already extended beyond the limits originally intended. It will be only necessary to observe, previous to an application of these principles to the dimensions of the ships composing the experimental squadron, that cases 5 and 8, form the chief exceptions to the general practice which at present exists in proportioning the length and breadth of our navy.

The Challenger, Tyne, and Sapphire, 28-gun frigates, toge-

ther with the Wolf, Acorn, Satellite, and Columbine, 18-gun corvettes, formed the experimental squadron which was placed under the command of Rear-Admiral Sir Thomas Hardy.

The following tables contain the principal dimensions, together with as many calculations on the ships as the writer of this paper has been able to obtain.

DIMENSIONS OF THE MASTS AND YARDS OF THE EXPERIMENTAL SQUADRON, AS ORIGINALLY FITTED.

	TYNE.		SAPPHIRE.		CHALLENGER.		WOLF.		SATELLITE and ACORN.		COLUMBINE.	
	Masts.	Yards.	Masts.	Yards.	Masts.	Yards.	Masts.	Yards.	Masts.	Yards.	Masts.	Yards.
	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.
Main mast	75.00	71.25	79.66	72.00	78.00	72.00	69.00	61.00	72.00	63.00	70.08	58.00
Main top-mast..........	45.00	52.75	48.75	55.00	48.00	54.00	42.00	46.00	43.16	45.66	39.41	41.00
Main top-gallant-mast ..	22.25	32.08	24.00	35.16	27.00	36.00	24.00	31.00	21.58	28.33	23.75	25.00
Fore mast	69.00	62.16	73.33	64.08	69.00	60.00	63.00	56.00	63.83	55.00	65.25	54.50
Fore top-mast..........	40.25	46.33	43.58	49.16	42.00	45.00	37.00	42.00	38.16	41.00	38.08	41.00
Fore top-gallant mast ...	19.66	28.33	22.00	31.33	21.00	30.00	22.00	27.00	19.08	25.00	23.75	25.00
Mizen mast, and gaff	63.75	36.91	61.50	35.16	55.83	34.00	57.33	33.00	60.50	31.91	64.41	
Mizen top-mast	33.00	35.16	36.00	36.00	36.00	36.00	30.00	31.00	32.41	31.00	39.58	
Mizen top-gallant-mast..	16.66	24.25	18.00	25.00	18.00	24.00	20.00	21.00	16.33	21.33		
Bowsprit, & spritsail yard	45.83	46.33	50.50		48.00	54.00	43.00	44.00	44.58	41.00	43.66	
Cross-jack yard		52.75		55.00		54.00		46.00		45.66		
Jib-boom	35.00		36.00		39.00		35.00		30.00		30.00	
Driver boom			48.66		45.00		42.00		43.16		37.50	

DIMENSIONS AND ELEMENTS OF THE EXPERIMENTAL SQUADRON.

	Length.	Breadth.	Ratio of Length to Breadth.	Depth in Hold.	Burthen in Tons.	Depth of Keel & False Keel below the Rabbet.	Area, in square feet, of			Displacement, in Tons.		Moment of Stability, in Tons, at 10° Inclination	Number of		By whom constructed	By whom commanded
							Midship Section.	Load Water Section.	Sails.	Light.	Load.		Guns	Men.		
	Feet.	Feet.		Feet.		Feet										
Tyne	125.00	32.54	3.84	9.75	600	1.58	303	3552	12656	461	810	675	28	160	Sir Robt. Seppings.	Capt. White.
Challenger	125.62	32.70	3.84	9.06	602	1.54			13432				28	160	Capt. J. Hayes.	Capt. J. Hayes.
Sapphire..	119.00	33.66	3.53	8.00	605	1.58	310	3621	14066	430	800	847	28	160	Professor Inman.	Capt. H. Dundas.
Acorn	112.00	30.50	3.67	7.83	455	1.50	240	2844	11500	297	572	528	18	115	Sir Robt. Seppings.	Capt. Ellis.
Satellite ..	112.00	30.50	3.67	7.83	455	1.50	240	2844	11500	291	585	528	18	115	Sir Robt. Seppings.	Capt. Laws.
Wolf	113.37	30.52	3.71	7.89	454	1.50			11763				18	115	Capt. J. Hayes.	Capt. G. Hayes.
Columbine	105. 0	33.18	3.16	7.91	492	1.22			10748				18	115	Capt. Symonds.	Capt. Symonds.

DRAUGHTS OF WATER, HEIGHTS OF MIDSHIP PORTS, &c. &c.

	Light Draught of Water.		Draught of Water.						Height of Midship Port.			Quantity of Ballast, in Tons.			Quantity of Water, in Tons.		
			Channel Service.				Foreign Service.		Channel Service.		Foreign Service.	Channel Service.		Foreign Service.	Channel Service.		Foreign Service.
			1st Cruize.		2d Cruize.		3d Cruize.		1st Cruize.	2d Cruize.	3d Cruize.	1st Cruize.	2d Cruize.	3d Cruize.	1st Cruize.	2d Cruize.	3d Cruize.
	Forward.	Abaft.	Forward.	Abaft.	Forward.	Abaft.	Forward.	Abaft.									
	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.						
Tyne	10.91	13.25	15.75	16.50	16.20	16.50	16.87	16.70	5.41	5.18	4.75	60	100	100	73		64
Challenger	10.54	13.20	15.75	16.33	15.91	16.25	16.58	16.58	5.54	5.50	5.04	90	96	96	85	90	85
Sapphire..	9.91	12.87	15.00	15.83	15.00	15.83	15.66	15.91	5.00	5.00	4.58	58	58	58	71	62	60
Acorn	10.00	11.83	13.91	14.91	13.84	14.91	14.75	15.00	5.86	6.00	5.50	49	69	69	50	50	50
Satellite ..	9.75	11.91	14.20	14.95	14.42	15.00	14.83	15.25	5.58	5.44	5.25	49	69	69	52	52	52
Wolf	10.33	10.60	14.60	14.60	14.62	14.62	15.04	14.66	5.41	5.39	5.16	50	61	61	52	54	52
Columbine	8.25	12.83	13.75	15.00	14.33	14.95	14.60	15.00	4.00	3.99	3.83	30	30	30	52	46	44

[1] Each of the ships, except the Wolf and Challenger, were fitted with cast iron limber boards, the weight of which is here added to the weight of the ballast.

From the general equality existing in the tonnage[1] of the ships of each class, it appears that their constructors were restricted in this particular; and that they had the choice of obtaining the required tonnage by any adjustment of length or breadth.

In one of the columns of the first table is inserted, the relative length of each ship, supposing its breadth to be denoted by unity. The most remarkable features in this column are,—1st, The great relative breadth of the Columbine above that of the frigates; 2dly, The great relative length of the Challenger and Tyne above that of the corvettes; each of which, as far as precedents should guide us, and as far as we may place reliance on the observation in case 1,—viz., "that the small frigate should be relatively broader than the large corvette,"—would have been the reverse.

We possess ample information respecting a numerous class of corvettes, built after the Bonne Citoyenne, as also respecting the small class frigates similar to the old Enterprise. A consideration of the dimensions and qualities of these ships may serve to ascertain the expediency of the relative dimensions given to the vessels of the experimental squadron; among the constructors of which vessels evidently existed a great difference of opinion, on their discretionary power of preferring length to breadth, or the reverse.

The Bonne Citoyenne, which was captured from the French in the year 1796, was 120 feet 1 inch long, and 30 feet 11 inches broad, or in the proportion of 3.88 to 1. This ship excited very great interest among naval officers: some extolled her excellencies, others depreciated her defects. It is probable that her qualities neither deserved all the applause of the former, nor all the disapprobation of the latter. The Ariadne, Hermes, Valorous, and Myrmidon, were built similar to her. The Bann, Cyrus, Leven, and many others, were also built similar to her, but on a reduced scale; their average length being 115 feet $7\frac{1}{2}$ inches, and breadth 29 feet 10 inches. All ships should, if possible, sail equally fast; but it has been

[1] The Columbine is an exception to this: her tonnage exceeds that of the Acorn, Satellite, and Wolf, by 38 tons. This, of course, gave her constructor greater latitude in the determination of her dimensions.

proved theoretically, that a ship, built on the reduced lines of another ship, will not possess the same velocity as the original. This truth was exemplified in the case before us, on a most extensive scale, fully proving that the numerous class of corvettes constructed similar to the Bonne Citoyenne, but smaller than this ship, were very inferior to her. If we have a ship whose qualities are generally approved of, it is an error either to build ships similar to her, by increasing or decreasing her length and breadth; as the larger ship would, in consequence, have too much stability, and the lesser too little stability, which is by far the greater evil. Thus, then, if we increase the size of a ship, we should give less relative breadth; if we decrease the size, we should give greater relative breadth.[1] As might have been foreseen from these principles, the reduced Bonne Citoyenne class of corvettes was found extremely defective in stability; all attempts to remedy this evil, by additional ballast, were fruitless; they only served to establish a general and a very important truth,—that where a great deficiency in stability exists in any vessel, abstractedly considered, a great increase of ballast must prove at least an inefficient, and, in most cases, a totally inadequate remedy, to so serious an evil. It was only after these experiments were made, that the want of stability in these vessels was assigned to the absolute cause,—deficiency in breadth. They were accordingly widened 10 inches, by placing a 5-inch fir doubling on each side, which increased their breadth to 30 feet 8 inches: the ratio between their length and breadth was then as 3.76 to 1.

By a comparison of this ratio with that existing between the Indian and old Merlin classes of corvettes, it will be seen that the general ratio of the length to the breadth, of English corvettes, is as 3.74 to 1. As these vessels were not remarkable for an excess of stability, it appears reasonable to conclude, that no corvette, at least of these classes, should be built, having a less relative breadth than is indicated by the above proportion.

From the agreement of the relative length and breadth of the Wolf, Acorn, and Satellite, with those of corvettes which have

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[1] For these reasons, we cannot expect that the Romney, Salisbury, &c., built on the reduced lines of the Christian VII., will possess equal sailing qualities with this ship.

not been deficient in stability, it may be inferred, that the dimensions of these ships are well regulated. A ship may have sufficient breadth, but may be nevertheless very crank. Whether the most eligible application has been made of the breadth of these ships, to ensure the necessary stability, becomes a totally different consideration, which will be hereafter attended to.

In further considering the dimensions of the experimental squadron, our attention must be directed to the small frigates; which have never been a favourite class in our navy. It has been the opinion of persons of considerable intelligence, that there is no need of an intermediate class between the 42-gun frigates and the large corvettes, and that the small class frigates might with propriety be substituted by powerful corvettes. There can be but little doubt, that this measure might be partially adopted, with great advantage to the service. A corvette may be constructed, with equal or less expense, which might be superior, both in velocity and armament, to the small frigate. Notwithstanding this, there are particular services and climates in which the small frigate would be more advantageously employed than the corvette: for instance, persons of distinction, as Ambassadors, &c., may embark and find sufficient accommodation in the small frigate, instead of employing larger ships for this service. This is of importance in an economical point of view. The frigate affords more personal comfort to the men, as they have always a dry deck for sleeping on; it is needless to add, that at sea, where many privations must be necessarily experienced, too much attention cannot be paid to the health and convenience of both officers and men, at least as far as the interest of the service will allow of it. Another remark may be made in favour of the small frigate, which is, that in case a yard or mast is shot away, the multiplicity of gear, &c., attached to it, will not incommode the working of the main-deck guns; whereas, if a similar accident were to happen to a corvette, several of her guns would be rendered completely useless, which might in a great measure occasion the loss of an action.

To return, from this digression, to our more immediate consideration. We may remark, that the ratio of the length to the breadth of small class frigates built in England, from the middle

of the last century to the present time, is about 3.58 to 1. The relative dimensions of the class built after the old Enterprise, as the Dido, Vestal, Mercury, Pegasus, &c., agree with this; as do also those of the present Volage. The Tweed, Ranger, Niemen, &c, being 3.6 times as long as they are broad, have rather more relative length than the above vessels. The old twenty-fours, as the Eurydice, old Champion, &c., built after the Amphitrite, have rather less relative length, being 3.54 times as long as they are broad.

From the knowledge we possess of the reduced Bonne Citoyenne class of corvettes, and likewise of the old class 28-gun frigates, the former being very crank, and the latter being sufficiently stiff,[1] two inferences may be drawn which may prove serviceable in the future design of these classes of ships. It in the first place appears, that if corvettes were found deficient in stability, with a ratio of length to breadth as 3.87 to 1, much more is the evil likely to be increased in designing small frigates, with the same or nearly the same relative length and breadth. Hence the superiority in stability of the old twenty-eights, and particularly of the present Sapphire over the Tyne and Challenger. Hence, also, the probable error made by the French in constructing the Tourterelle, Jamaica, Astrée, Valeureuse, and the Fortunée.

We may, 2ndly, infer, that if small frigates are not too short, which are 3.57 times as long as they are broad; that a corvette must certainly be too short which is only 3.16 times as long as she is broad. Hence may arise the inferiority of the Columbine to the Acorn and Satellite, when sailing against a head sea.

From the consideration of the ratio between the length and breadth of these ships, we may proceed to inquire into the effect thereby produced on their stability. Among the many difficulties attendant on the design of ships, from our imperfect knowledge of the nature of fluids, and of hydrodynamical science in general, it fortunately happens, that their stability

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[1] The old 28-gun frigates took a very great quantity of ballast,—in some cases, from 180 to 200 tons: if this be urged as a proof that these ships had not sufficient stability, it will be a stronger argument in favour of the conclusions which follow.

is capable of being determined with comparative accuracy. We are enabled to ascertain the absolute stability of a ship, and may consequently express in known quantities how much it is greater or less than that of another ship. Were this element calculated for all ships, it would lead to a more correct determination of the relative dimensions of each class: it would enable us to ascertain to what extent the breadth of a ship should be increased by carrying heavier metal: thus, what addition should be made to the breadth of our first-rates, by their being armed with 32-pounder guns on the middle deck, instead of 24-pounders? We should avoid the error of constructing a line of battle ship, which, from her not being able to use her lower deck guns in heavy weather, might be captured by a frigate. These advantages, without the enumeration of others, will suffice to show, that the construction of ships may be greatly improved, by enlarging our knowledge respecting their stability; but to enter into this inquiry in a manner which may produce any important result, the height of the centre of gravity is required, which point has never yet been experimentally ascertained for any ship of this nation.

On this account, we are unable to state in what degree the stability of the various ships of the experimental squadron differed. But, from the quantity of ballast, the difference of form and breadth, and their behaviour at sea, we may form a general idea on the subject. That there is a great difference between the stability of the Sapphire and Challenger, appears from the quantity of ballast taken on board each ship. The Challenger first proceeded to sea, with 50 tons of ballast; a few hours' trial proved the absolute necessity of increasing her stability; she accordingly returned, and 20 tons more ballast were added. Still, not being found sufficiently stiff, her ballast was increased, before she sailed with the squadron, to 90 tons, which, on the second experimental cruize, was made up to 96 tons: she at the same time stowed 28 tons more water than the Sapphire, making a total difference of weight, materially contributing to the stability of the Challenger, of 66 tons.

From the near equality between the breadths of the Tyne and Challenger, it was to be expected, that if one were found deficient in stability, the same defect would be found in the

other. This was verified by experience. When the Tyne sailed from Woolwich she stowed 60 tons[1] of ballast, which was ultimately required to be increased to 100 tons.

Notwithstanding the Challenger and Tyne had so considerable a quantity of ballast more than the Sapphire, it was evident, from the comparative inclinations of these ships, when under equal sail, that the Sapphire was by far the stiffest ship; proving the propriety of affording the necessary stability, by an increase of breadth, instead of attempting to gain this indispensable quality by a great addition to the ballast.

We are not to suppose, from the latter remark, that a consideration of breadth alone, will enable us to estimate the stability of a ship. Were this the case, it would have been found that the stability of the Columbine would have far exceeded, and the stability of the Wolf would have been equal to, that of the Acorn and Satellite; whereas it did not appear, except at small angles of inclination, that the Columbine was much stiffer than the Acorn and Satellite; and it was apparent that the Wolf was not so stiff as either of these vessels. We may conclude from this, that the bodies of the Acorn and Satellite, between wind and water, were more advantageously formed, for contributing to stability, than those of the Columbine and Wolf. We must, however, bear in mind, that the Columbine, as well as the Sapphire, possessed sufficient stability, with a considerably less quantity of ballast, than was necessary for the other vessels of their classes.

In forming a correct judgment on the properties of a ship of war, we should suppose her under the most trying circumstances in which she can be placed. These appear to be when engaged with an enemy in a heavy sea, under a press of canvas, blowing fresh. If a ship in this situation is not able to fight her lee and weather guns, whatever excellencies she may possess in other respects, she is certainly inefficient in the very essential quality required in a man of war.

That a ship may use her guns with effect in heavy weather, she must not only possess sufficient stability, but she must also carry her ports a sufficient height out of water. From the

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[1] Including the weight of the iron-limbers.

preceding table, it will be seen, that in the third cruize, when the ships were stowed for six months, the ports of the Challenger and Tyne were a few inches higher than those of the Sapphire; that the ports of the Acorn were rather higher than those of the Wolf and Satellite, and that there was the material difference of 20 inches between the height of the Acorn's ports and those of the Columbine. But as the angle of inclination of the deck to the horizon, is not a less important consideration than the height of ports out of water, it is obvious that no superiority in the latter respect can compensate for a deficiency in stability. On this account, the Sapphire is superior to the Tyne and Challenger, in efficiency as a ship of war; as are also the Acorn and Satellite to the Wolf. The Columbine would experience a similar difficulty in firing her guns, in heavy weather, as the Challenger, Tyne, and Wolf, although proceeding from a different cause. She is certainly a stiff ship, but this excellency is greatly compromised by the lowness of her ports, which, with her foreign stores on board, were only 3 feet 10 inches above the water. If we suppose the Columbine engaged with an enemy, under moderate sail, when blowing very fresh, at an inclination of 8°, (which is far from being an extreme case,) her midship port would be only 18 inches out of water. Any person at all acquainted with the subject, must be aware of the impossibility of her firing her guns in this case, if there was the least swell at the time. The defect of the Columbine, in this important particular, shows the necessity, when making a design of a ship, of correctly estimating the weight of the hull, men, guns, provisions, and stores of every description; and if science were of no further service, in naval architecture, than in giving ships sufficient displacement, it would prove of no inconsiderable benefit.

The capability of using their guns in heavy weather, was, with respect to several ships of the squadron, fully decided by experiment. On the morning of the 29th of September the squadron was under all possible sail, the wind being extremely light, and the water smooth. Towards noon the wind increased considerably, with rather a heavy swell; about 2 P.M. the admiral made signal for the ships to fire their guns: they were

then under courses, double-reefed topsails,[1] top-gallant sails, jib, and driver. In consequence of the inclination of the Challenger (12°), and on account of the water rushing into her ports, she was unable to fire her guns with any effect; the range of the shot was extremely small. The Alert and Wolf were found equally incapable of using their guns; whereas it appeared that the Acorn and Satellite might have engaged an enemy, even under their heavy press of sail.

It may be urged, that the ships were put to a more severe test than could arise in practice, inasmuch as no vessel could engage an enemy under so much sail, when blowing equally fresh. The truth of this assertion is very questionable; but if it be admitted in its fullest extent, there can be no doubt that actions may take place when blowing much stronger, and in a heavier sea, so that if sail be shortened (as it necessarily must be), the angle of inclination of the ship, from the increased power of the wind, might be the same, or greater, and as much difficulty would be found in firing the guns in the latter case as in the former. The Tyne, Columbine, and Sapphire, were not in company with the squadron on the above occasion.

Among the principal qualities required in a ship, may be noticed commodious stowage. A ship should not only have space to stow her provision and furniture of every description; but they ought to be stowed with particular regard to convenience, in order that they may be immediately procured in case of emergency. Stores of a perishable nature should, as much as possible, be placed in situations where every attention may be paid to their preservation. Utility should never be sacrificed to an appearance of spaciousness and neatness in the store-rooms of a ship. In the practical superintendence of stowing a ship, considerable skill is displayed by some officers, which may be greatly aided by a good disposition of the hold. No more divisional bulk-heads should be built in a ship than are absolutely required; both for giving increased room, and circulation of air. In the Sapphire and Acorn, the after hold and spirit room were thrown into one, with great

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[1] The Challenger had all the reefs out of her main and fore topsails.

advantage; and as the fore magazine[1] was capable of containing all the powder, the space which was occupied by the after magazine was, in the Sapphire and Tyne, included in the bread room. Care is particularly necessary in placing the bulk-heads, as it often happens that a tier of tanks in the hold, or a tier of casks in the after hold or spirit room, is lost, on account of a bulk head being a trifling distance too far forward or aft. On this account, it was found necessary to alter the bulk-heads of the Wolf and Challenger from their original situations. If the cubical contents of the Columbine's hold were estimated, they would be found less than those of the other corvettes; but her constructor has, in a great measure, remedied this inconvenience, by judicious arrangements. Instead of putting oak pillars in the centre of the lower deck beams, and placing tanks on each side of these pillars, it was found that the Columbine's body was of such a form, that more water could be stowed by placing small cast-iron pillars on each side a-midships. That no space might be lost, a few small tanks were made expressly for this ship; and as a ship may be supposed to wear out a set of tanks, no objection can be made to this measure, in an economical point of view.

It is very probable that many persons place an undue importance on considerable stowage, from not reflecting, that serious inconveniences may be thereby incurred. Of two nations, the one which stows its ships for a shorter period than the other will possess the more efficient navy, as far as velocity is concerned. Our ships, generally speaking, take a greater proportion of stores and provisions than the ships of any other nation. It becomes, then, a question of some importance, whether the advantages gained, by enabling ships to keep the sea longer, more than counterbalance the evil which must arise from a diminution of velocity? Strong arguments may be advanced on both sides of this question. For general service, ships should be constructed, as much as possible, to unite both advantages. Perhaps it would be advisable, for

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[1] Among other improvements adopted by Admiral Willaumez, in a powerful frigate, lately built by him in France, may be noticed, that of having a grand magazine in the centre of the ship, with various communications from it, for facilitating the supply of powder to the different guns.

particular services, to build ships for the express purpose of velocity. In line of battle ships, which may be employed in blockading an enemy's ports during several months, without the possibility of obtaining water, except from the uncertain supply afforded them by transports, &c. considerable stowage is absolutely necessary. The case, however, is very different with smaller ships, inasmuch as they may be generally considered to be employed on services in which they will have sufficient opportunities of procuring water. On this account, and from each of the ships of the experimental squadron being enabled to stow six months' provisions and stores under hatches, (which is a period double what is considered necessary in ships of similar classes in other nations, for instance, the Danes,) neither of them can be considered deficient in this important particular, although some are superior to others: thus, the Challenger stows more water than the Sapphire and Tyne; and the Columbine is, in this respect, inferior to the Wolf, Acorn, and Satellite. We may have occasion hereafter to decide, how far increased stowage was found beneficial, as it regards the sailing qualities of some of these ships, particularly of the Challenger and Wolf.

It would be impossible by verbal description, without a reference to the draughts of each of the ships of the experimental squadron, and making calculations on their bodies, to convey an accurate idea of their forms. They have all rising floors; and, with the exception of the Columbine, have a hollow, from the keel to the floor-heads. The water-lines of the Sapphire, Challenger, Columbine, and Wolf, are hollow abaft; those of the Acorn and Satellite are round, excepting a slight inward curvature at the lower part of the bottom. We may in some degree judge of the comparative fulness of their fore and after bodies, by referring to the difference between their light draughts of water forward and abaft; thus—

The Tyne	was	2ft.	4in.	by the stern when launched.
Challenger	—	2	8	ditto.
Sapphire	—	2	11½	ditto.
Acorn	—	1	10	ditto.
Satellite	—	2	2	ditto.
Wolf	—	0	3½	ditto.
Columbine	—	4	7	ditto.

There is not sufficient difference in the quantity which each of the 28-gun frigates was by the stern after launching to indicate a material variation between them, in the relative fulness of their fore and after bodies. Not so, however, with respect to the corvettes. The Acorn and Satellite were much finer abaft than the Wolf, which was only $3\frac{1}{2}$ inches by the stern, and the Columbine had evidently a still finer run abaft than either. We may here remark, that the constructor of the Tyne has pursued the same principle, in giving a fine after body to this ship, which is a frigate, as well as to the Acorn and Satellite, which are corvettes; on the contrary, the constructor of the Challenger has given this ship, which is a frigate, a fine after body; but to the Wolf, which is a corvette, he has given a particularly full after body.

The most remarkable difference of form exists between the Columbine and Wolf. The Columbine has so full a fore body, that in order to get her by the head, her ballast was stowed before the main-mast; the Wolf has so full an after body, that to get her sufficiently by the stern, her ballast was placed abaft the main-mast. The forms of the Acorn and Satellite appear to be a mean between these extremes, as their ballast was more equally concentrated about the main-mast.

The relative breadth of the Columbine, perhaps, exceeds that of any other ship of equal tonnage ever built. The form of the Columbine is in a great degree, like the forms of the corvettes Heureux, Determinée, and Garland, and the 32-gun frigate Barbadoes, each of which was taken from the French. Her fore body is very full; on the contrary, her after body is remarkable for its fineness, so much so, that in order to obtain the requisite space on deck, her counter flairs out in almost an horizontal direction.

The Sapphire, Tyne, Acorn, Columbine, and Satellite, were fitted with iron-limbers, the weight of which being placed low down, formed an advantageous substitute for ballast. The Wolf and Challenger had angular pieces of wood secured on each side of their keels, in order to oppose a greater lateral resistance to going to leeward.

Before entering into a brief statement of the sailing of the ships, during the three experimental cruizes, we may remark,

that when sailing close-hauled, the harder it blows, the greater advantage may the corvette be expected to have over the small frigate; because the more sail is reduced, the more sensibly will the greater surface of the weather side of the frigate, above that of the corvette, be felt in its tendency to drive her bodily to leeward. A detailed account, specifying the advantage one ship had over another, at the conclusion of each day's trial, would prove unsatisfactory, from the difficulty of correctly estimating distances at sea; on which subject persons of considerable experience frequently differ. It also appears unnecessary, inasmuch as it would be evidently improper to estimate the properties of the ships by adding together the number of days they were first, second, and so on, and to judge of their merits accordingly; without taking into consideration the varieties of weather, to which they were exposed. Moderate wind and smooth water were most frequent, which proved particularly favourable to some vessels; but a decision, founded on their behaviour on these occasions, would have been an injustice to those vessels, which excelled in a head sea and in heavy weather. If we are enabled to form a generally correct opinion of the qualities of the ships, by pointing out those circumstances in which they excel, and those in which they are defective, with the probable reason of success or failure assigned to the proper causes, it is to be presumed this is all that can be required.

The squadron weighed anchor, and proceeded on the first cruize, on April 5th, 1827. The Admiral hoisted his flag on board the Pyramus, Captain Sartorius. The manner in which the various trials were conducted, was as follows:—A particular ship was sent a few miles to leeward; the rest of the squadron, with the exception of the flag ship, then closed round her, under easy sail; on the Admiral hoisting the signal for making sail, each of the ships hauled her tacks on board, and the trial commenced. The quantity of sail set by each ship was always left to the discretion of her commander. At the termination of the trial, the superiority or inferiority of the different ships was estimated, by conceiving parallel lines, drawn through each ship at right angles to the direction of the wind, and ascertaining the distances between these lines; which shows how far the

different ships were to windward or to leeward of each other, independent of the distances they were a-head, or a-stern. When sailing free, the merits of the various ships were determined by the respective distances they were a-head of each other, measured in the direction of their course.

It may be here observed, that although in most cases we may form a general idea of the strength of the wind, by the quantity of sail set by a ship, yet we should be liable to considerable error, if we form a similar judgment with reference to the sail set by this squadron. These ships often carried an immense press of canvass, as much, indeed, as it was possible for the spars to bear; and it was no uncommon occurrence for them to carry single reefed top-sails and top-gallant-sails, when ships in ordinary circumstances would have had nothing above double reefed top-sails.

The squadron was joined, during this cruize, by the Trinculo and Alert: these were built from the same draught, and formed part of the numerous class of gun brigs constructed by the late Sir William Rule. The Alert was rigged as a ship, and the Trinculo according to the original design, as a brig.

With respect to the sailing qualities of the 28-gun frigates, in the first cruize, when stowed for channel service, in moderate breezes, close-hauled, the Challenger was rather superior to the Sapphire; when blowing hard, was equal to her; and sailing free, was inferior to her. The behaviour of the Tyne, during this cruize, was generally inferior to that of the other ships of the squadron.

A similar comparison among the corvettes will show, that in the first cruize, in light breezes, close-hauled, the Columbine was usually superior to all the ships of her class, but that there were occasional instances in which she was beaten by the Wolf and Satellite. The Acorn, Trinculo, and Alert, were in moderate breezes leewardly, when compared with the above ships. When blowing hard, sailing close-hauled, against a head sea, the Satellite was rather superior to the others; the Columbine, Trinculo, and Wolf, were about equal to each other; the Acorn was generally, and the Alert always, inferior to the Satellite, Columbine, Trinculo, and Wolf. When sailing free, the Columbine beat all the corvettes; the Acorn was rather supe-

rior to the Wolf and Satellite, which were about equal to each other; and the Trinculo was a faster sailer than the Alert.

In the foregoing remarks, the sailing qualities of the frigates and corvettes have been separately alluded to. If we compare these two classes of ships together, it will be decidedly in favour of the frigates, except that the Columbine was superior to them when sailing close-hauled in smooth water; but, even in this case, they frequently proved themselves the most weatherly ships. As far as we may judge from the behaviour of the Alert and Trinculo, of the propriety of altering these vessels into ships (taking velocity only into consideration), it is certainly against this measure, as the Trinculo was evidently the superior vessel. The Pyramus, although a powerful frigate of 42 guns, could no more compete with the vessels of this squadron on a wind, than the Thetis and Phæton could with the Orestes, Pylades, and Champion, which composed the former experimental squadron. This fact alone is sufficient to prove that we have of late years made some advances towards improvement;—that the Leda class of 46-gun frigates, of which we have a great number in the service similar to the Thetis; as also the 42-gun frigates, similar to the Galatea, are very inferior ships, as far as regards velocity, which, next to efficiency in action, is the most essential quality a ship should possess.

On the return of the squadron to Portsmouth, such alterations were made in some of the ships as the experience of the first cruize dictated. It was found that the Sapphire often lost, in a few minutes, by tacking, the advantage which she had gained over the Challenger and other ships during several hours by forereaching; notwithstanding the Challenger's being the longer ship, and must therefore oppose more resistance in going about. The cause of this difference appeared to be, that the Sapphire worked so quickly, that the head-yards were seldom braced round, before she payed off considerably on the other tack: this was more particularly apparent on May 4th, when she had beaten all the squadron in a long reach of four hours, but was ultimately weathered by the Challenger, after twice tacking. It appeared that the head sails acted at too great a mechanical advantage, by being placed so far from the axis of rotation. The fore mast was accordingly moved 12 inches, the

main mast 6 inches, and the mizen mast 3 inches farther aft. The Sapphire, on some occasions of light winds, carried a slack helm. The above alterations in the situations of the masts, by bringing the centre of effort of the wind farther aft, would produce a tendency to remedy this evil. The roaches of the courses being unnecessarily high, the main mast was shortened 8 inches, the fore mast 2 feet 2 inches, and the mizen mast 6 inches. No diminution was in consequence required in the area of the sails.

The Acorn, during some part of the first cruize, was leewardly, and carried her helm sometimes a-lee. When the squadron put into Bantry Bay, during the first cruize, more rake was given to the masts of this ship; she was brought more by the head, and supplied with 12 tons additional stone ballast; these alterations had the desired effect; she afterwards worked better, held a better wind, and never carried a lee helm. On her return to Portsmouth, she received a new main mast, 3 feet longer, which was placed 14 inches farther aft than the original one: the mizen mast was brought 2 feet 6 inches farther aft; the main course was increased 6 feet in the drop; the stone ballast was taken out of her, and 20 tons more iron ballast were shipped. Angular pieces were placed on her keel, for the reasons which have been mentioned for placing such pieces on the keels of the Challenger and Wolf.

The Satellite was supplied with 20 tons additional ballast, and her main top-mast was increased 4 feet in length.

It was found necessary to remove the Columbine's main mast 14 inches, and her fore mast 10 inches farther aft, in order to improve her helm, which she frequently carried a-lee. The length of her main top-mast was increased 3 feet. The main top-gallant mast was reduced 18 inches; the bowsprit was shortened 20 inches, and 6 inches more stive was given it at the outer end. She was supplied with a main yard 6 feet longer, a main topsail-yard 5 feet longer, and a main top-gallant yard 4 feet longer, than the original yards; the length of the driver boom was increased 5 feet, and that of the gaff 4 feet: these alterations in the dimensions of her spars, made an addition to the area of her canvass of about twelve hundred square feet.

The following are the dimensions of the masts of the Tyne, as she was fitted for the second cruize:—

	Feet.
Main mast	81.33
Main top-mast	48.75
Main top-gallant-mast	24.33
Fore mast	71.75
Fore top-mast	43.00
Fore top-gallant-mast	21.50
Mizen mast	68.00
Mizen top-mast	36.58
Mizen top-gallant-mast . . .	18.42
Bowsprit	50.42

These enlarged masts produced a great increase in the area of her sails, which was now about equal to that of the Sapphire and Challenger. In order to improve her stability, she was supplied with 40 tons more ballast; and angular pieces, as in the Acorn, were secured to her keel.

The squadron proceeded on the second cruize, on June 30th, 1827. The Admiral hoisted his flag on board the Galatea, 42 guns, Captain Sir Charles Sullivan. The Acorn was commanded by Captain Gordon. The prevailing winds, throughout this cruize, were extremely light; indeed, during many of the trials, the wind lulled to a perfect calm. The advantage which the Challenger gained over the Sapphire and Tyne, during the second cruize, in moderate breezes, close-hauled, was much greater than in the preceding cruize: this, however, appeared to decrease towards the termination of the cruize, when the Challenger became lighter on account of the consumption of provisions. The Tyne was evidently improved by the alterations which were made in her, both as it respected stability and weatherly qualities. She had an occasional advantage in light winds, over the Challenger, but more frequently over the Sapphire.

When comparing the qualities of the frigates, on those days on which it blew half gales of wind, sailing against a head sea, it was found that the Sapphire was superior to the Challenger, and the Challenger to the Tyne. The Tyne, however, on one of these occasions (August 17th,) behaved extremely well, as

she was equal to any ship of the squadron. Sailing free, the Sapphire was still superior to the Challenger, and the Tyne was inferior to both.

In making a similar comparison between the qualities of the corvettes in this cruize, as has been done with respect to the frigates, we may first remark, that a very material improvement was manifest in the Columbine, by the alterations which were made in her. When sailing close-hauled, in light winds and moderate breezes, her superiority over every ship in the squadron was very decided. This was more particularly apparent on July 16th, in a fresh top-gallant breeze, when, in the course of nine hours, she beat the Challenger (which was the second ship) between six and seven miles dead to windward. The Alert, which was the most leewardly ship, was at least ten miles to leeward of the Columbine, at the conclusion of the trial. This was, however, the only day on which the Columbine obtained so very great an advantage.

It remains to mention their sailing qualities in the third cruize, when they were stored and provisioned for six months.

As the qualities of the squadron became more fully known, it was found necessary to bring the ships more nearly on an even keel, and even in some cases by the head. It is remarkable that it should have been proved by experience, that seven ships, built by different constructors, of various forms and proportions, were all improved by bringing them more nearly on an even keel.

The chief alterations of importance, made in the vessels previous to the third cruize, were in the Acorn, the main mast of which ship was reduced to the original length. The squadron got under weigh from St. Helens on the 25th of September. Captain Harrison was in this cruize appointed to the command of the Challenger, in the room of Captain Hayes.

The weather throughout this cruize materially differed from what was experienced in the former cruize, as the squadron encountered a continued succession of nearly gales of wind. The Sapphire, which was generally inferior to the Challenger, in moderate breezes close-hauled, in the former cruize, was in this cruize superior to her, as was apparent on September 25th, which was the only day (except on October 6th, when it was

occasionally calm,) on which a trial was made under these circumstances, when she was beaten only by the Columbine.—When blowing half a gale of wind, with a heavy head sea, the Challenger was also unable to compete against the Sapphire. The same remark is equally applicable, when sailing free.

It is to be regretted, that the Tyne was separated from the squadron during the greater part of this cruize. The only opportunity of judging of her qualities was on October 6th, when her behaviour appeared to indicate a material improvement in her, as, with the exception of the Columbine and Sapphire, she beat the squadron.

Of the corvettes, the Columbine still maintained her decided advantage over them, in moderate breezes, close-hauled. The Wolf, in these cases, was no longer equal to the Acorn and Satellite. The same defect appeared in this ship, with her foreign stores on board, as was evident in the Challenger, which was, not possessing sufficient velocity through the water.

We may form a general opinion of the qualities of the squadron, during this cruize, when blowing hard, by noticing their behaviour on October 8th. In this trial, their qualities were accurately defined, and proved that in heavy weather, when sailing against a head sea, the order of superiority was, Acorn, Sapphire, Satellite, Columbine, Challenger, Alert, Wolf; but when sailing on the tack on which they had not to contend against a head sea, the order of superiority was, Columbine, Satellite, Acorn, Sapphire, Challenger, Wolf, Alert. It may be here noticed, that although the Columbine was inferior to several ships when sailing against a head sea, she would frequently nearly compensate for this deficiency on the other tack, as was the case on the above occasion.

Having given a general idea of the behaviour of the experimental squadron, during the three cruizes, we may separately allude to their respective qualities. In all attempts to draw conclusions, or to form comparisons of the relative performances of ships, there are numerous circumstances which exist or occasionally occur to render the task one of considerable difficulty: much of the good or bad performance of vessels must depend on the experience, judgment, and energies of the commanders; delays may be occasioned by accidents which, as

they may not be apparent, cannot be accounted for; the uncertain and variable nature of the winds, and in fact, so complicated are many of the circumstances which affect the sailing of a ship, that it is hardly possible to account for the difference of her behaviour at different times. Thus, on one occasion, May 4th, in a fresh top-gallant breeze, the Wolf beat the whole of the squadron to windward; whereas, on another, May 10th, she was the most leewardly ship; the quantity of sail set in each case was the same, and there was no apparent variation in the nature of the sea, or in the strength of the wind. Other similar instances might also be adduced.

The Sapphire, when sailing on a wind, excels in a head sea, blowing hard: she is a weatherly ship in light and moderate breezes, and is a very fast sailer off the wind. She has good stability, is easy in pitching and rolling, and possesses good accommodation for her officers and crew. Her stowage would have been improved by more depth in hold, and her ports should be a few inches higher out of water; but, taking her qualities altogether as a ship of war, she is the finest of her class in the service.

The Challenger, when stowed for channel service, behaves extremely well; either sailing close hauled or free, in moderate breezes, or when blowing hard; but she has not sufficient stability. When stowed for foreign service, her stability is improved, but her velocity is greatly diminished. She has great capacity for stowage, which cannot be fully made use of, without proving very injurious to her sailing. She carries her ports well out of water; her accommodations for officers and men are good; and she is very easy in all her motions.

The sailing qualities of the Tyne, when stowed for channel service, in the first two cruises, were very generally inferior to those of the Sapphire and Challenger. Of her behaviour when stowed for foreign service, we can only form an idea from one day's trial in moderate weather, on which occasion she behaved very well. She is easy in all her motions, possesses good accommodations for officers and men, is not deficient in stowage, but has not sufficient stability.

The Columbine when sailing close hauled in smooth water, has extraordinary weatherly properties. When blowing hard,

she does not excel sailing against a head sea, but on the other tack, she nearly compensates for this deficiency. She sails very fast off the wind; has very commodious decks for fighting her guns, and working the ship: is rather confined in stowage; possesses good stability, but which is greatly compromised by the lowness of her ports. The great fineness of her after body occasions heavy 'scending, which produces a tendency to work her fastenings; besides which this peculiarity of form cannot be considered the most advantageous for a ship, in case she is taken aback in a heavy gale, or when scudding.

The Acorn and Satellite, when sailing close hauled in moderate breezes, are weatherly ships; but their superiority is chiefly evident when sailing against a head sea, in a gale of wind. When blowing fresh, they sail very well off the wind, but not so well in light winds. In other respects, they possess the good properties of the Columbine, with the additional advantage of carrying their ports higher out of the water; and in their general efficiency may be considered two of the finest corvettes in the service.

The properties of the Wolf appear to be very similar to those mentioned when referring to the Challenger, as her sailing is greatly injured when stowed for foreign service. When stowed for Channel service, in moderate breezes on a wind, or sailing free, she behaves very well; neither can she be considered deficient in weatherly properties when blowing hard. In accommodation, stowage, and carrying her ports well out of water, she is equal to most ships of her class, although the form of her body is not so adjusted as to contribute to her stability.

These cruizes have shown us, that ships of very dissimilar forms and proportions may sail well. For a ship to answer, she must possess stability, small resistance to going a-head, and great resistance to going to leeward. We may easily conceive that several varieties of form may conduce to these effects; some in a greater, others in a lesser degree: and that, what is lost by one peculiarity of form, may probably be gained by another.

It is not, however, the form of a ship which alone contributes to her sailing. The setting up of her rigging, the trim of the

ship, the concentration of the ballast towards the middle of the length, and the angle to which the yards are braced, are considerations of the greatest importance to the properties of a ship. The angle to which the main-yards of most of the ships of the squadron were braced, when sailing close hauled, varied between 27° and 30°; whereas the Columbine's main-yard was braced to an angle of 19°, and frequently to an angle of only 17°. On this account, and from her being rigged as a bark, she possessed many of the advantages of a fore and aft rigged vessel. Another thing which is probably of equal, or even more consequence, than any of these to the fast sailing of a ship, especially when on a wind, and indeed which is absolutely necessary to give her the full advantage of the properties she may possess, is the cut of and manner of trimming the sails: this is a point in naval science, to which too much consideration cannot be given.

It was intended to have entered more fully into the properties of these ships, but the already extended length of this paper prevents it. It may be naturally asked, how far this experiment has forwarded science? If no new truths have been elicited, it has at least confirmed many opinions which have of late years been frequently advanced in this country:—1st, That the quantity of ballast may be considerably reduced, as is evident from the Sapphire and Columbine. 2d, That we may with propriety increase the breadth of ships, as is evident in the Columbine. 3d, That the after bodies of ships may be made much finer than they usually are, as is also evident from the Columbine; although it does not appear advisable to carry this to the extent which is done in this ship: the same remark is applicable to the breadth of ships. 4th, That the draught of water may be diminished, as has been in some degree done in the Sapphire; and 5th, It becomes doubtful, whether the yards of ships when sailing on a wind, may not be braced much sharper than is warranted by present custom.

PAPERS

ON

NAVAL ARCHITECTURE,

&c.

Art. IX.—*On the Rise, Progress, and present State of Naval Architecture in this Country: in two Lectures delivered at the Royal Institution of Great Britain, on the Evenings of Friday the 2d and Friday the 16th of May, 1828. By* John Knowles, Esq., F.R.S., *and communicated by him.*

Lecture I.—The advantages of Naval Architecture, to countries whose local situation enables them to enter into maritime and commercial pursuits, need not be long insisted upon by me in this place. By the means of ships, civilization is promoted, affording, as they do, intercourse between nation and nation, however remotely situated: by this, the luxuries, nay, what may, through habit, be considered the necessaries of life, are more generally diffused; and thus the more favoured countries by climate are enabled to pour forth their superabundance, to meet the wants or wishes of nations to whom nature, or the God of nature, has not been equally bountiful. But, to Great Britain, ships have conferred more signal and lasting benefits. To go no further back than our own times, when for twenty years the sword and fire ravaged most of the countries of Europe, the navy of England gave to this country the commerce of the world; and, by protecting her shores inviolate from foreign invasion, afforded peace and happiness at home.

In showing the rise and progress of naval architecture in England, the observations which I shall have to offer will necessarily have relation to some of the data upon which this science

depends; and that I may not be misunderstood in these, I shall first explain, in as familiar a manner as I can, some of the leading principles.

I acknowledge my inadequacy to do this, in a satisfactory manner, before so learned and scientific a body as the members of the Royal Institution; and must therefore beg, in the words of a learned critic in another art, that the indulgence which, in justice, you must refuse to my powers, you will grant to my will.

In a rude state of society, when man first trusted his body to the water, it is more than probable that he employed some extraneous aid to float him, and, for the purpose, used some substance which he saw always swimming upon its surface, or, in other words, which was specifically lighter than the water itself. This would lead to his rendering such bodies still more buoyant and useful to his purposes, by allowing their volume of displacement to remain the same, and decreasing the weight, by making them hollow; such as we witness in the canoes of men who have been, at times, discovered by circumnavigators in nearly a savage state. From such beginnings, as man advanced in civilization, and required floating bodies of greater capacity, for various purposes, so he contrived to put several trees together, and construct a raft, and subsequently to form hollow vessels to contain goods. Thus, step by step, he arrived at the regular construction of ships; varying their size, form, and displacement, according to his wants, or to meet local circumstances. A correct knowledge of the displacement of a floating body is highly necessary for a variety of purposes; the principal of which are,—1st, It enables a naval architect to ascertain the fact of the absolute weight of a ship, when light and when loaded; and, 2dly, In designing ships of war, the constructor of the draught being already aware of the weight intended to be put into the ship, arrives, by this, to an exactness at the height at which the portsills will be above the line of fluitation,—a most important consideration; for, in times when methods of calculating the displacement of ships were either not known, or not practised, fearful accidents arose to them, to which I shall have occasion to advert more particularly in the course of this lecture.

Since science has shown that the volume of water displaced by a ship is equal, in weight, to that of the body which causes it to be so displaced, and as the bodies of ships are composed of irregular curves, some difficulty arises to come at their solid contents. Hence several methods have been devised, some mathematical and others mechanical, to arrive at the fact of a ship's displacement. It would be foreign to my purpose to enumerate these in their order of time: suffice it to say, that all of them, for usefulness and elegance of application, have given way to one introduced by Chapman, a Swede, who, by assuming upon the plan of a ship's body a load-water-line, drawing others equidistant therefrom, and delineating the forms described by these several lines in a longitudinal direction, and then measuring, by means of equidistant ordinates, their distances from a right line, and applying to these a formula (which he gives) derived from the parabolic curve, to which the forms of ships approximate, the displacement is determined with sufficient accuracy. And this operation leads to finding the centre of gravity of the displacement, and also the stability of a ship, by a point called the metacentre.

The stability is the next element of importance in naval construction. It is that power which the body exerts to retain or regain an upright position, when under the influence of any force tending to incline it: such as the force of the wind upon the hull of the ship above water, and upon her sails, or the mal-position of any weight placed on board. Ships of similar dimensions, with regard to length, breadth, and depth, will vary in stability according to the greater or less area of their lines of fluitation (upon the extent of which this quality mainly depends), according to the form of their bodies at, below, and above, this plane, and according to the weights in the ships, and their respective distances from the centre of gravity.

As it is desirable that ships should have as much of stability by form as can be advantageously obtained, so it is necessary that the area of the plane of fluitation, and the sections parallel to that plane, for some distance above and below it, should be as great as convenient. This not only raises the centre of gravity of displacement, but causes the stability to increase as the body inclines by the force of the wind. Care, however, should be

taken by the constructor, that the solids of immersion and emersion are properly regulated, so as to prevent an uneasy motion when the ship rolls. To add to stability, the ballast should be placed as low down as it can be, consistent with easiness of motion.

When science was called to the aid of naval constructors, it became with them an object of the greatest importance to find a measure, which might be depended upon, of the stability of ships of the same class. Bouguer turned his attention to this subject, and produced an elegant and sufficiently correct method, which was, to determine a centre or "point in the vertical longitudinal section, which divides the ship into two equal or similar parts, below which the centre of gravity must necessarily be situated, in order that it may float upright." This he called the metacentre. The centre of buoyancy, or displacement, naturally alters its position according to the immersion of the body; and as the metacentre is dependent upon this centre, so it will also be liable to change its situation: and as the comparative measure of stability is, as the respective distance of the metacentre from the centre of gravity of the ship, so it is evident that, in the same vessel, the stability will be variable. It may be right here to remark, that, under ordinary circumstances, the centre of gravity of our ships of war is generally at, or a little below, the line of fluitation.

It has been stated, that the vertical sections of ships approximate in their form to parabolas. Chapman has given a formula, derived from the parabolic curve, by which the metacentre also may be easily and correctly found. I am aware that this method of determining the comparative stabilities of ships, is open to some objections. Atwood has proved this, in a paper published in the Philosophical Transactions, and has there given a very laborious method of finding their stability. But I repeat, the metacentric method is preferable, as it is easily determined, and, when found, is sufficiently correct for all practical purposes. Atwood's method requires much labour, and occupies a length of time in coming at the result, and is of course liable to the errors common to all lengthened calculations.

Numerous as have been the theories of the resistances of

fluids, yet, after the most laborious investigations, aided by experiments, no accurate law has been established. Hence the difficulty which attends the naval architect to ascertain the forces which act upon a ship when put into motion, to regulate the position of her masts, and to place the extreme breadth or greatest section in the most advantageous position for velocity.

It would be foreign to my purpose, in this place, to enter into what has been advanced by mathematicians, particularly by Euler, of the degree of resistance which it is probable a vessel meets with in a direct or in an oblique course, what is due to the bow or fore part of the ship (called the *plus* pressure), or how much to the stern or after part (the *minus* pressure), or what to friction. I shall state what has been ascertained: that, *cæteris paribus*, the resistance which floating bodies meet with in passing through the water, is as the area of their greatest section, and that the resistances increase as the squares of the respective velocities. From the former of these principles, it will appear how important it is for ships to have as small an area of midship section, as other considerations will admit of.

The motive power usually employed to propel ships, is the force of the wind exerted upon canvas sails, which are spread and directed in a proper position, according to the intended course of the ship, by means of masts and yards. The position in which these masts and yards should be placed in the ship, and the proportion which they should bear to its stability, are circumstances of the highest importance. As the stability of ships (if advantage be taken of their principal dimensions) increases in a geometrical ratio with their respective breadths; while, with regard to length, it only increases arithmetically: so the height of the masts should be determined by the breadth of the ships, and the length or spread of the yards by their length. And these for several reasons: vessels having great stability can bear sails carried up much higher, and the masts are better supported for the purpose, by the more obtuse angle which the shrouds make in broad, than in narrow, vessels. And although, in long and narrow ships, the area of the sails may be equally as great, or greater, yet they do not act so powerfully to incline the body as when there is a longer lever.

I might have remarked, in the few observations which have been offered upon the resistance of fluids, that until some law is established on this point, the proper situation of the masts in ships cannot be laid down theoretically. This must therefore depend upon experiment. There is no doubt that a difference in the forms of ships' bodies will affect their position, particularly that of the fore-mast and mizen-mast, so as to preserve a balance of sail, and that the ships may perform their evolutions quickly and well, and, what is important to this, that they carry a weather-helm: that is, when they are under sail, and going on, or with a side wind, that the tiller be inclined a little to that side whence the wind blows; but not so much so as to impede velocity. In those of our three-masted ships of war, in which the masts are considered to be properly situated, the fore-mast is placed abaft the after part of the stem 1-9th the whole length of the ship, the main-mast 5-9ths, and the mizen-mast 6-7ths. In deference to the practice of some men of high name and established credit, I am disposed to think that the foremasts, in some of our ships recently built, have been, for a variety of reasons, placed too far forward.

When the position and dimensions of the masts and yards are determined upon, there are other considerations to be observed, with regard to their security: such as, the angle and position of the shrouds and stays placed for their support; and that these shall prevent, as little as is practicable, the yards being properly braced, in order that the force of the wind may be advantageously applied for propelling the ships in their intended course. Euler gives, as the best disposition of the sails, when the vessel is close hauled, 21°, with the wind abeam 32°30′, when going large or right before the wind 57°. But, in practice, the shrouds prevent the yards being braced, when the vessel is close hauled, seldom less than 30°, by which power and other advantages are certainly lost.

It may be remarked, in this place, that the shape or cut of the sails is an important point; for if, when it is intended that they shall be sharply braced, there should be a considerable curvature in them, it will not only impede the velocity of the ship, but increase the lee-way.

To prevent accidents likely to arise from sudden gusts of

wind, the moment of the force of the wind upon the body of the ship, and upon her sails, should be so regulated as to be considerably less than the ship is able to bear from the moment of her stability. But by giving due consideration to this point, by regulating the extent, and, consequently, the power of the sails to the stability of the body, such accidents are not to be apprehended in large ships, where their stability is great, as the material of which their sails are made (canvas) would give way and be destroyed by the force of the wind, before the ship would be heeled to an angle at which danger is to be apprehended. As a general axiom, however, the power of the sail should be so adjusted to the stability of the ship, that, under ordinary circumstances, the inclination should never exceed seven degrees: for, besides the many inconveniences to which the seamen are put, on board those ships which heel more than this angle, their velocity is diminished; as the area of the sails, and the force with which the wind acts upon them, are both decreased in proportion to the inclination.

It has been already stated, that, every thing else being equal, the comparative resistances which floating bodies meet with in their passage through the water, are, as the respective areas of their broadest section. This fact being established, it has led to an important change and great improvement in ships of war of most nations: for, in order to decrease the area of the midship section, it has been found necessary to give a greater proportion of length to breadth to the ships, so that they may still have sufficient displacement and stability.

Experience seems to have determined that the following are the best proportions of length to breadth, the length being taken at the water-line from that part of the stem against which the planks abut, to a similar place at the stern-post, and the breadth, at the line of fluitation:—In first-rate ships of 120 guns, having three principal decks, 3,75 times as long as they are broad; in second and third-rates, varying from 84 to 74 guns, and having only two principal decks, from 3,75 to 4 times their breadth for length: the larger the ships, the greater should be their comparative length to breadth; in fourth-rates (frigates from 60 to 50 guns), from 3,9 to 4 times their breadth for length; in fifth-rates (frigates from 50 to 42 guns), 3,9 times

their breadth for length; in sixth-rates, 28 guns, 3,6 times their breadth for length; in corvettes, 3,8 to 4 times as long as they are broad; brigs, 3,27 as long as they are broad; and in cutters (a vessel peculiar to the English), 3 times as long as they are broad.

Such being the principal elements of naval construction, I shall now proceed to give some account of the rise and progress of naval architecture in this country.

The foundation of the naval power of England was laid by Alfred, who, when he ascended the throne in the year 871, found that the military force was not sufficient to repel the Danes and other invaders who had so often disturbed the tranquillity of England, and that all his views of the internal improvement of the country would be frustrated, if invasion were not prevented. He determined, therefore, to build gallies (for of such a nature was the naval force of most countries at this time), which should surpass, in size and power, those usually sent over by his most formidable enemies, the Danes. In the fourth year of the reign of this king, we accordingly learn, that his galleys were numerous, that they were twice as long as those of Denmark; therefore adapted for velocity, and better calculated for the intended purpose. The form of their bodies, and character of these vessels, having been contrived by Alfred, he may, therefore, be considered (in the order of time) the first naval architect for ships of war of whom England can boast.

This wise policy was not followed, either by Edward, Athelstan, Edmund, Edred, or Edwy, the immediate successors of Alfred; and therefore England suffered from invaders during their reigns, and was obliged frequently to purchase an ignominious, and always precarious, suspension of hostilities.

When Edgar mounted the throne (in 959), he adopted the same line of policy which had marked the reign of Alfred, and the navy rose to a height which it had never before attained. He divided his numerous fleet into three squadrons, which were constantly kept cruizing, the better to afford protection to the shores of his kingdom. But the navy again fell into decay during the reign of Ethelred, which favoured the invasions of the Danes, and obliged him several times to purchase of them a disgraceful peace.

Edmund II. succeeded his father in the year 1016, and, being a man of great physical powers, and a soldier, naturally depended for the safety of the kingdom upon similar qualities, and therefore raised a considerable army. But when Canute succeeded him, he pursued a different system, and raised a marine force for the protection of the kingdom.

Harold neglected the navy, for, like Edmund, he considered that his own and kingdom's safety depended upon his army; and when threatened with invasion by William of Normandy, he did not even employ the naval force which he possessed. This false policy and oversight cost him both his crown and his life.

The conquest of England by William, in 1066, gave to this country a great accession of ships, of all the descriptions then in use; and the navy was manned with excellent seamen, well trained by the constant intercourse, which there then was, between this country and the ports in Normandy. At this period, the sovereignty of the narrow sea between England and Normandy was claimed by William, to which he considered he had a title, the shores of the two countries being his; and hence the denomination of "the British Channel."

It is only fair to presume, that, during the reigns of William Rufus, Henry I., Stephen, Henry II., and Richard I., embracing a period of rather more than a century, the navy was not neglected; for the sovereignty of the narrow seas was maintained; and the fleet of England, during the reign of John, who came to the crown in 1199, was sufficiently respectable, in force and numbers, not only to claim this right, but the right of the whole of the seas: for it was enacted at this time, that "if the masters of foreign ships should refuse to strike their colours, and thus to pay obedience to the English flag, such ships should be considered lawful prizes."

During the long reign of Henry III., the navy was suffered to go into decay; and he lost the respect which this country had for some time previously maintained by its naval force. This arose partly from his distaste for maritime affairs, but chiefly from his disputes with his Barons, who prevented those supplies being afforded, from the cinque ports, which the crown had been accustomed to draw from them. So low was the navy in

the year 1269, that all the force which Henry was able to collect, to accompany his son Edward and nephew Edmund in a crusading expedition to the Holy Land, was thirteen small vessels, capable of containing about 1000 soldiers and followers.

Little is known of the naval force during the reign of Edward I.; but Edward II. appears to have paid much attention to shipping, and to have introduced some important changes therein. Gallies had been hitherto employed as vessels of war: this monarch ordered larger ships to be built for that purpose, to be propelled either by sails or by oars, and which, from being higher out of the water, gave safety to their crews and decided advantages in employing those implements of warfare which were then in use.

A question naturally arises,—Of what nature were the ships at this time, and how were they armed? Although, after the gallies had been discontinued, a larger class of ships was introduced, called galleons, yet it is evident, from the number of vessels which was required to convey but a small body of troops for even a short voyage, that they were not of a large size; and if we may credit the delineations on coins and old prints, they were rude in form, fitted with one mast only, and little capable of performing voyages, except the wind blew on the shore to which their attention was directed. In the middle of these ships machines were placed, for projecting darts or stones; and forward and abaft were castles, in which archers and cross-bow men were placed: but when they came to close quarters, the sword was the weapon used. We shall find the circumstance that ships had castles at this period, afore and abaft, verified by a letter in Robert of Avesbury's '*Historia de Mirabilibus Gestis Edwardi tertii*,' of which the following is the translation:— "Be it remembered, that our Lord the King and his host landed at Hogue de St. Vaal the 12th of July. He found at the Hogue eleven ships, of which eight had castles before and behind, the which were burnt. And on the Friday, whilst the king remained there, some troops went to Barfleur, and expected to have found many people; but they saw none, and they found there nine ships with castles before and behind, ij good craiers, and other small vessels, the which were burnt.

And the number of ships which were burnt is sixty-one of war, with castles before and behind."

But during this, the fourteenth century, two important circumstances took place, which altered the nature of naval architecture altogether: the first, the discovery of the mariner's compass, in the year 1302; and the next, the introduction of cannon, which were first used by Edward III. at the battle of Cressy, in 1346; and no doubt, from the impression which they then made, were shortly afterwards put into ships of war.

The application of magnetic attraction, to direct ships in their course upon the ocean, or the introduction of the mariner's compass, is due to Flavio John de Gioja, a native of Amalfi, in the kingdom of Naples, who, by this invention, rendered the most important service ever conferred upon mankind. Navigation, owing to the fears of mankind, was, prior to this period, confined to the coasting trade, in small vessels of slight draught of water; or if a voyage to the opposite shores of a foreign country was attempted, it could only be performed when the wind was fair, to drive the ships thither, and in weather when, in the night, the stars were not likely to be obscured by clouds. This infant state of navigation is thus described by Dryden:—

> "Rude as their ships was navigation then,—
> No useful compass or meridian known;
> Coasting, they kept the land within their ken,
> And knew no north but when the pole-star shone."

But when the compass was introduced, ships of large burthen were built, men put fearlessly to sea, into deep water, losing sight of land, and depending upon this useful instrument for their course.

The introduction of cannon on board ships made it necessary to increase their dimensions and strength, in order to allow of their carrying this additional weight above the line of fluitation. And when port-holes were cut in the sides, through which the guns were to project and be fired without injury to the fabric of the ship, (which however did not take place until the year 1500,) it then became a consideration of moment that the ships should have their portsills a sufficient height from the

water, to prevent accidents from the ingress of the sea, when in an agitated state, or when they were inclined by a press of sail.

Little, if any thing, worthy of notice can be traced respecting the state and progress of the navy during the reigns of Richard II., Henry IV., V., VI., or of Edward IV. and V.,—a period of 106 years. And although Richard III. held the office of Lord High Admiral of England, when Duke of York, yet he appears to have lost sight of the navy when he came to the crown.

Henry VII. had other and better views: he felt that the glory and safety of his empire depended upon its naval force; and he probably was the first king, since Alfred, who constructed ships expressly for naval purposes. The Great Harry, of 80 guns, of which there is a beautiful model now before me, was laid down by his direction, but was not completed till the commencement of the reign of his son, Henry VIII. Earlier than this period, the commencement of the reign of Henry VIII., there are but few documentary facts respecting the navy; so that the historian is obliged to be content with these, and to fill up his narrative with conjecture. But now we have some guides which are to be depended upon: I mean, the pictures of the able artists of those times, whom the liberality of Henry induced to reside in this country, and, what is still more important to naval architects, the model now on your table; for which the government is indebted to the liberal views of Mr. Holdsworth.

But let us pause for a time, to examine this model, and point out its peculiarities. The length of this ship, at the water-line, was 138 feet; her breadth, from out to outside, 36 feet; and the draught of water in midships, 22 feet 8 inches: this draught of water, I should premise, is not conjectural; as the learned and accurate Raleigh stated, that when she was loaded, the portsills were not more than sixteen inches out of the water. The height of the middle of the ship above the line of fluitation, was 22 feet 7 inches.

It will appear evident, even from a cursory inspection, that, from the number of guns with which this ship was armed, and the number of men necessary to work them, that she was not of sufficiently large dimensions to give the requisite displacement, so as to carry the ports a proper height above the line of

water. Nor was the proportion of breadth, as compared to length, sufficient to give a ship, so high out of the water, particularly forward and abaft, and so overloaded with cannon, a proper degree of stability; the want of which was proved particularly in this ship, and another constructed about the same time, and consequently upon the same principles,—the Marie Rose, which sunk with all her crew (more than 400 men) at Spithead, by filling with water taken in at her ports, in an attempt to wear when the French fleet appeared off that anchorage; and the Great Harry nearly suffered the same fate, in performing some naval evolution. Added to these, the draught of water of the Great Harry was considerably more than half her breadth; a circumstance always to be avoided, as, generally, ships are not found to answer well at sea, whose immersion exceeds one half their main breadth at the water-line.

Having adverted to her construction upon some of those principles which practice has established as a law, and which are to be accounted for upon mathematical reasoning, I shall now proceed to direct your attention to the peculiarities in her build, and in her masts, yards, &c.

The first thing which strikes us is, the round bow with its projecting prow: this forms embrasures with loop-holes, and is decorated at its extremity with a lion, which extends thirty feet from the stem. The overhanging stern next comes under observation: this projects twenty feet from the line of support by the water, and is ornamented with cumbrous carved work, and further loaded with two castles. This formation of the prow and stern, by their height and weight, caused the body to be unstable, and also increased the motions of pitching and 'scending. The wales, which are now worked much thicker than the other planking, and placed close to the timbers of the frame, are, in this model, brought over the planking, and, to give additional strength to the topsides, abutment pieces are placed between the posts, from the upper wales to a thick strake called the string in the waist. The hawse-holes, through which the cables pass when a ship lies at anchor, are here placed on the middle deck: it is presumed that this was done from necessity, the lower deck (the position where they are now usually cut through) being too near the water. There are four

castles on each side, probably for cross-bow men. It is also to be remarked, that this ship has what is called a square tuck; and that the ports in her sides come one over the other, which no doubt would be found very inconvenient in action, from the fire proceeding from the upper guns flying into the ports immediately under them; and certainly this arrangement was very detrimental to the general and uniform strength of the ship. There were, it will be perceived, five lower masts, or, as they are usually termed, four lower masts and a bowsprit. The topmasts are not affixed to the lower masts, but are stepped merely in the tops, as also are the top-gallant-masts; and both owe their security only to the shrouds and stays. The lower shrouds are brought within the ship, which would be always advantageous, if they would form an angle sufficient for the proper support of the masts, as, by this arrangement, the guns run out clear of the rigging. But in the case now before us, it was no doubt very impolitic: as the ship was very narrow, so the masts received an insufficient support from the shrouds.

This model will serve to explain some of the terms in naval architecture, which were then very properly applied; and they are still continued in the navy, although a change of practice has rendered their meaning nugatory. Here we see that the deck called the quarter deck, is nearly one fourth the length of the ship; the term is now used, although the deck is at least equal to half the length. The forecastle, now so called, is defended by castles; and hence the term. The tops, it will be perceived, are round; and although now they are nearly a square, yet it is not unfrequent for seamen to call them "the round tops." The bowspreet is one stick, without a jib-boom; and no doubt we get the term "bowspreet" from a sprit or stick placed in the bows. I could pursue this subject, but the inquiry would be more curious than useful.

The Great Harry continued in the service until 1553, in which year she was burnt by accident at Woolwich.

Prior to the reign of Henry VIII., ships were furnished for the service of the state, by the cinque ports, for which they enjoyed peculiar privileges and immunities, or they were either purchased or hired of merchants at home, or procured from the Hanse-towns, the Venetians, the Genoese, or other foreign

nations. But Henry appreciated the advantages which the government would derive by having, at all times, within its own power the means of building, repairing, or equipping a fleet; and he therefore established dock-yards,—first at Woolwich, then at Deptford, and finally at Portsmouth,—and appointed a Navy Board for their management. And, in order to induce the merchants to build, for the purposes of commerce, such ships as would be suitable for warfare if necessity required their services, an Act of Parliament was passed, exempting them from certain duties to which other ships were subjected. When they were required by the crown, the rate of hire was 12*d.* per month for every man employed on board them. And for the furtherance of naval architecture, and that all the knowledge of the times might be taken advantage of, he hired Italians, then the most esteemed workmen in shipbuilding in Europe, and distributed them among his shipwrights, for the imitation and instruction of the latter.

Notwithstanding these excellent measures of Henry to establish a marine, the navy, during the reigns of Edward VI. and his sister Mary, was not only stationary with regard to improvement, but retrograded in numbers and importance: so low was it at the accession of Elizabeth, that it consisted only of 46 vessels, and many of these were of a small size.

When Elizabeth succeeded to the crown (in 1558), she followed the politic views of her father, and was very intent upon improving the naval force of the kingdom. During her reign, a period of forty-five years, the navy was doubled in numbers, and the ships were constructed of a larger size. Hitherto guns of dissimilar calibres had been placed upon the same deck, to the inconvenience and annoyance of the gunners. This was remedied by an order, that all the guns on the same deck should be of a similar calibre, and no ship was to carry more than 60 guns.

The indefatigable and politic Raleigh directed his attention to the navy, and contributed much to its improvement. With a view to increase the stability of ships, he recommended a much greater proportion of breadth to length than had hitherto been given; for he says, in his 'Observations on the Navy and Sea Service,' that " one hundred feet long and thirty-five feet

broad, is good proportion for a great ship." Thus, in wishing to improve an essential quality, he exceeded, in this particular, all bounds of moderation. During this reign, some of the most important machines and improvements connected with naval architecture were introduced: among the former may be instanced the chain pumps, which, notwithstanding a multitude of trials of other pumps of various constructions, still, for usefulness and simplicity of construction, keep their ground in our navy. The capstand, for weighing the anchors and performing other important work on board ships, was also invented at this time; and, among the latter, a method of striking the topmasts was introduced, and the cross pillars or braces (which were claimed in the latter part of the eighteenth century, as an invention, by a man of some ingenuity, the late Mr. Snodgrass,) were then practised; for Sir Walter Raleigh says, "We have added cross pillars in our royal ships, to strengthen them, which be fastened from the kelson to the beams of the second decke, keepe them from setling or from giving way in all distresses."—Again, in the furniture of ships, additions were made; for we find that the bonnet and drabbler, the stay-sails and studding-sails, were then introduced. The building of large ships in merchants' yards, for the royal navy, was deprecated by Raleigh, who says, "Great mischief accrues to the service by building in *private* yards, and I strongly recommend that no large ship should be built except in royall yards, for all such ships did not endure." In order, then, to avoid this, and provide for the necessities of the state, Elizabeth commenced, in the river Medway, an additional arsenal, now termed Chatham Dockyard.

Sir Robert Dudley, afterwards Duke of Northumberland, a man of enlarged views and comprehensive mind, paid also much attention to naval affairs: he proposed to lower the forecastles and sterns of ships, and to abridge their then cumbrous ornaments; to raise their lower batteries, and to increase their length, so as to make it equal to four times their breadth. But as his views did not meet with the encouragement which he expected from the government, he constructed a ship at his own expense, and made a voyage to India in the year 1594. It is to be remarked, that Sir Robert gave the plan of a vessel which he

called a "frigata," very similar to the frigates of the present day.

The spirit of enterprise and improvement in naval architecture, which marked the reign of Elizabeth, continued during that of James 1st, who came to the crown in 1603. He appointed commissioners to inquire into the state of the navy, to examine into the quantity and condition of the stores, and to offer suggestions for the preservation, maintenance, and improvement, of ships. He also chartered "the Shipwrights' Company," to whom was given, for examination and approval, all the draughts for building ships for His Majesty's service. This company made laws for the governance of the body of shipwrights, and had the power to punish those who broke them, either by fine or imprisonment.

But what contributed most, at this time, to the improvement of naval science, was the appointment of Mr. Phineas Pett, a man not only of great ability, but of learning, first to the situation of naval constructor, and finally to that of Commissioner of the navy. In the year 1610, this able naval architect constructed a ship to carry sixty-four guns, called "Prince Royal," this ship was considered a master-piece of the art, and is thus described in Stowe's Annals: "This year the king builded a most goodly ship for warre, the keel whereof was 114 feet in length, and the cross beam was 44 feet in length; she will carry 64 pieces of ordnance, and is of the burthen of 1400 tons. This royal ship is double built, and is most sumptuously adorned within and without, with all manner of curious carving, painting, and rich gilding; being, in all respects, the greatest and goodliest ship that ever was builded in England. And this glorious ship the king gave to his son Henry, Prince of Wales; and the 24th September, the King, the Queen, and Prince of Wales, the Duke of York and Lady Elizabeth, with many great Lordes, went unto Woolwich to see it launched; but because of the narrowness of the dock, it could not then be launched: whereupon, the Prince came the next morning by three o'clock, and then, at the launching thereof, the Prince named it after his own dignity, and called it the Prince. The great work-master in building this ship, was Master Phineas Pett, gentleman, some time Master of Arts at Emanuel College Cambridge." If

we might credit the representation of this ship, given by a plate in Charnock's Marine Architecture, this art would indeed have made a great and rapid stride, within a very few years. But notwithstanding the opinion of this able author, in favour of the authenticity of the drawing, yet, by comparing it with a well authenticated draught of the "Sovereign of the Seas," built also by Mr. Phineas Pett in 1637, twenty-seven years posterior to the "Prince Royal," I think there is every reason to believe the drawing not to be genuine, for it appears to me, that it is a much nearer approach to the improved state of ship building, in the time of Charles II., than "the Sovereign of the Seas" was, and must therefore have been delineated some years after that ship was constructed.

When Charles came to the crown, he showed the same disposition to improve his marine force, as had marked the conduct of those of his predecessors, who had advanced the glory or prosperity of England; and to improve, as he said, the navy, a tax was levied upon the trading and commercial towns, which went to compel them either to supply a certain number of ships, or a stated sum of money, under the denomination of "ship money" which caused much discontent, and finally cost him his crown and his life.

From the money thus raised, Charles was enabled to build a magnificent ship at Woolwich, called "the Sovereign of the seas," which was, as has been observed, from the design of Phineas Pett. The progress made in naval architecture, during little more than a century, will be best appreciated by comparing the model of the Great Harry, with the drawing of this ship now before us. It will be seen, that a first rate of three decks, in the reign of Henry VIII., was only 138 feet in length, and 36 feet in breadth; while, the Sovereign of the seas measures 167 feet 9 inches in length, and 48 feet 4 inches in breadth; the former being only of the size of a small modern frigate, and the latter somewhat smaller than the modern 74 gun-ships.

It will be right to explain, that it is my intention, in all cases, to compare ships by length and breadth, as a much better criterion than the builder's tonnage, the latter having been calculated upon different principles at different times; and at

present, it gives but an imperfect notion of the capacity, or powers, of a ship.

It has been before shown, how deficient the Great Harry was, with regard to two at least, of the elements of construction, displacement and stability. But, if we carefully examine the drawing of the Sovereign of the seas, and submit the lines of the body to the rigorous test of those established mathematical rules which experience has proved to be correct; we shall find, that no better form could have been devised, for a ship built (according to the prevailing custom of the times) so high out of the water, and so overloaded also with ornaments. It is to be recollected, that Phineas Pett, the constructor of this ship, was a graduate of Cambridge, an university in which the mathematics have always been fostered, and have formed a favourite branch of study. In this ship, then, we see the triumph of science over the unaided talents of other times, and if we were not acquainted with the cause, the progress made in so short a period would create our surprise. In the sequel, I shall more particularly draw your attention to the advantages which naval architecture has derived, and may further derive, from the sciences. But it is to be lamented, that this need be insisted upon in the nineteenth century.

But to return to the examination of the drawing, or rather of that part of it which shows what the ship was above water. The midship ports, or those nearest the line of fluitation, are 5 feet from the water, giving her, as a ship of war, a great superiority over those built in former reigns. We see that the beakhead, common to the gallies of former times, was not then discontinued, for it extends here, 44 feet from the line of support from the water. And the stern, which has an additional poop, usually called the poop-royal, not only overhangs much, but is 51 feet 6 inches in height, from the water line to the taffrail.

Contemporary authors state, that more than ordinary care was taken, in collecting proper materials for the construction of this ship, in which the king himself took great interest, and frequently visited Woolwich Yard, to see the progress made in building her. The design and execution of the carved work were the best of their time. The figures and emblems must have been imposing to the eye of the spectator, as they were

gilt, and relieved by a black ground. In fact, this ship was not only celebrated for her magnificence of structure, but also for her good sea-going qualities, notwithstanding her height above water, an excess of which, must necessarily be very detrimental to a ship's good qualities. When the Royal Sovereign was cut down a deck, she was then the best ship of her time, and was employed in the service until the year 1696, when she was burnt by accident at Chatham.

It is to be feared, that your patience is already exhausted. I shall therefore now close my discourse, and on a future evening, pursue the inquiry, and to render it more interesting, finally introduce to your notice the improvement made in naval architecture at the present time, by the genius of Sir Robert Seppings; and, which I hope to elucidate to your satisfaction, by comparative models.

Lecture 2.—I concluded the discourse, which I had the honour to deliver from this place, with showing the advantages which naval architecture had derived from science, and its rapid progression when conducted by a scientific man; and brought down my remarks to the end of the reign of Charles I.: I shall now resume the subject in the order of time.

During the Commonwealth, the naval power of England arrived at a height to which it had never before attained. As the Dutch were then the most powerful enemies at sea, and the British ships, from size, fully equal to compete with those of Holland, so, no increase took place in their dimensions. But in the nine years that Cromwell conducted the affairs of this country, the navy, in numbers and force, was doubled. In 1649, a frigate called the Constant Warwick, was built by Mr Peter Pett, as a privateer for the Earl of Warwick, this was the first ship of that description constructed in England, and was, shortly after being launched, purchased by the state. But it is only justice to remark, that the merit of invention is not due to Mr. Peter Pett, for such ships had been previously built by the inhabitants of Dunkirk. The Constant Warwick carried 42 guns of different calibres, namely, 20 demi culverins which carried shots weighing 9½ pounds each, 18 sakers, and 4 light

sakers, carrying shots of $5\frac{1}{2}$ pounds each; notwithstanding this, the ship in question was not of larger dimensions than the present sloops of war of 14 guns, her keel being only 85 feet in length, and her breadth 26 feet. This ship remained in the service until the year 1691, when she was captured by the French. Frigates, at this time, however, were dissimilar in form and arrangement to those which bear that name at present; they carried guns on two decks, some had four or more heavy guns on each side, placed on a lower deck near to the water, to be used when the weather would permit, with a regular range of lighter guns on a deck above. While others had two regular tiers of guns. I must repeat that frigates nearly similar to those at present in use, were proposed, many years anterior, by Sir Robert Dudley.

At the restoration, Charles II. found the navy numerous and in good condition, but being negligent of every thing which did not contribute to his pleasures, he expended but little money on ships, and consequently the fleet went into decay. Charles nominated his brother James, then Duke of York, Lord High Admiral: this Prince with the advice of Mr. Secretary Pepys, first constituted the Navy Board a board of common council, and directed that records should be kept of their proceedings, so that each officer might know the transactions of the others; he issued a book of instructions for their guidance, and also for that of the officers of the dock-yards, and so perfect were these instructions, that they have served as the foundation for most subsequent regulations. During this reign, the first ship to carry 74 guns (the Royal Oak) was built (in 1674); this ship, however, was much smaller than some of our modern frigates of 48 guns, being only 157 feet 6 inches in length on the gundeck, and 41 feet 4 inches in breadth. She carried, notwithstanding, 28 demi cannons, a gun equal at least to our modern 32 pounders, 28 whole culverins equal to 18 pounders, 16 light sakers equal to $5\frac{1}{2}$ pounders and 2 three pounders. The frigates were increased in size, and, consequently, in capacity, as those previously built had their ports, when equipped for sea, only three feet from the water, those that were constructed at this period carried theirs four feet six inches. In the year 1670, metallic sheathing was first intro-

duced, it was milled lead fastened to the ships' bottoms with copper nails. In order to give it a fair and extensive trial, the bottoms of twenty ships were covered therewith; it was soon found, that weeds adhered to the lead, and that the rother irons were in a short period of time destroyed by oxidation.

Charles himself conducted the affairs of the navy from the years 1673 to 1679, and the miserable state of the ships of the line, at the latter period, when his brother James returned to the post of Lord High Admiral, is given in Pepys' "Memoirs of the Royal Navy" published in 1690. That the fleet was then in bad condition there can be no doubt, but there is good reason to believe, that the defects of the ships were magnified by Pepys, in order to show how much the navy had suffered, during the absence of James, and to raise the character of his patron for activity and good management on his return to office. I assert this from the fact of the short period of time in which thirty ships of the line were repaired and rendered sea-worthy, which could not have been done, with magazines of stores said to be exhausted, if their defects had been as extensive as Pepys wished to establish, for it would appear by his account, that they were in a sinking state at their moorings.

The Dutch continuing to be the most powerful of our opponents at sea, it was considered necessary to have a naval arsenal, as near to their shores as circumstances would admit; a dock-yard was consequently commenced at Sheerness.

The advantages which naval architecture derived during the reign of Charles I., by the appointment of a learned and scientific man, Mr. Phineas Pett, to construct draughts for ships of war, and the progress which, in consequence, it had made during a very limited period, appears to have been lost sight of by his son, for we learn from the accurate Evelyn, that some of those who practised this art during his time, were among the most ignorant of mankind. In his memoirs we find this remarkable passage:—"1668—3 March was launched at Deptford, that goodly vessell the Charles. I was neere his Majesty, she is longer than ye Soveraine, and carries 110 brasse canon; she was built by old Shish, a plaine, honest carpenter, master builder of this dock, but one who can give very little account of his art by discourse, and is hardly capable of reading, yet of greate abilitie in his calling."

On the accession of James II. to the crown, he continued to hold the office of Lord High Admiral, and to pay great attention to naval affairs: all the ships which had fallen into decay, during the previous reign, were repaired and refitted, and the magazines replenished with stores. While England was increasing her marine, France was not inattentive to the same object: Louis XIV., having a great desire to possess a navy of large and efficient ships, consulted men of scientific attainments, as to the best mode of constructing their bodies, and also navigating them; and encouraged the best mathematicians of that time, to promote naval science by their writings. Among those who added to the stock of knowledge at this time, may be mentioned the celebrated Pére la Hoste. The result of these inquiries went to increase the size of the French ships of all classes, which led to an increase in those of England; but, after a short time, we, in imitation of the Dutch rather than the French, relapsed to our former practice. The Comptroller of the Navy, at this period, was Sir Richard Haddock, who, being aware of the pains which other nations were taking to improve their marine, and feeling the importance of applying a degree of scientific knowledge to the construction of English ships, as a preliminary step caused a table to be made of the solid contents of the immersed part of the body of a ship of each class. This was the first table of the kind constructed in England, to serve as a guide to architects to give a sufficient degree of capacity to their ships: and that this might not be lost sight of for the future, Sir Richard promulgated (in March, 1692,) the method by which this table had been formed.

At the abdication of James II., in 1687, the navy was, in point of numbers, on a very respectable footing. William and Mary, however, increased its numerical force, and established on our western coast a dock-yard, that at Plymouth, now become one of the most important in the kingdom. The ships of this period were of small dimensions, overloaded with guns, and, in consequence, so unstable or crank as to be dangerous; and it was considered expedient to add to the stability of those of the line, by what was called girdling them; which was done by fastening strakes of plank, six or more inches in thickness, on each side, at a little above, and for some distance below, the

line of fluitation. This, in point of stability, was equivalent to giving them so much more breadth; and it increased their strength at a part where it is the most required. It may incidentally be remarked, that, in the year 1700, the Marquis of Carmarthen gave a simple and very useful improvement to the navy,—that of falling pauls to the capsterns: these prevented the many accidents to which the seamen had been previously subjected in weighing the anchors of ships.

At the demise of King William, the navy was in a very respectable state, both as it regarded the number of ships and their condition; but Queen Anne, his successor, directed her whole attention to the army: for, while the French were improving their ships, by giving encouragement to the study of the theory of naval architecture, and also increasing their numbers, the fleet of England was totally neglected. But as the navy has generally been a favourite service in this country, the apathy of the government with respect to it caused great murmurs among the people.

The conveniences which result, particularly upon foreign stations, from having the masts, yards, rigging, and sails of ships of the same class alike, are too obvious to be insisted upon: hence the dimensions of ships, their masts, yards, rigging, and the number and calibre of their guns, have been established at different periods. The first of these establishments on record is of the year 1677, which was confined to ships of the line of 100, 90, and 70 guns. In 1691, dimensions were given for the 80 and 60-gun ships. These establishments remained in force until 1706, when a regular classification took place for ships of all rates. A notion of the progressive increase in the size of ships may be judged of by the following comparison:—A ship of 90 guns was, by the establishment of 1677, to be 158 feet in length, and 44 feet in breadth; by that of 1706, it was to be 162 feet long, and 47 feet broad. Still the dimensions of the latter were very inadequate to the guns which she was to carry. Notwithstanding all the conveniences which arise from these establishments, it would not be difficult to show that they are barriers to improvement in naval architecture, as they necessarily assume the science to have arrived at the limits of its perfection,

To prove how difficult it is to construct a good ship, where limits shall be fixed with respect to dimensions, it will only be necessary to instance the case of the Royal Katherine, of three decks and eighty guns, built during this reign; which ship was designed by the Council of the Royal Society, at a time when Newton was actively engaged in its affairs, and pursuing inquiries intimately connected with naval science,—that of finding the solid of least resistance. Yet this ship was found to be so deficient in stability, that it was deemed necessary to girdle her. Our ships, previously to this time, were overloaded with carved work, which, for design and execution, was then (and I regret to say the little applied is now) a disgrace to the taste and talents of England. In 1706, the ships were relieved from, and the country spared the expense of, a great deal of this cumbrous work.

When George I. came to the throne, in 1714, the fleet was considered to be nearly worn out, and, in the succeeding year, this was proved to be the fact at a general survey which then took place. Consequently, vigorous measures were taken by him to repair some ships, and build or rebuild others. In 1716, a new establishment of guns was ordered by the king in council for all classes of ships, from a first-rate to a 20-gun ship inclusive: by this establishment, some of the first-rates were to carry 42-pounder guns on their lower decks. The weight of ordnance thus ordered to be placed in the ships, rendered it necessary to increase their size above the establishment of 1706; and therefore, in 1719, another table of dimensions received the sanction of the government. The first-rates of 100 guns remained as they were formerly established; but the second-rates of 80 guns were increased thereby two feet in length and one foot in breadth; and the other classes in proportion. Notwithstanding this, the English ships of war were of less dimensions than those carrying the same number and nature of guns built by most other nations. Such was the state of naval architecture during the reign of George I. His son, George II., was as zealous as his father had been in providing a numerous and efficient fleet; and at the commencement of his reign a survey was taken of the magazines of naval stores, in order to ascertain their condition and value; and, from these, several ships were ordered to be built.

The want of stability in the ships, to carry the guns established for them in the year 1716, was still complained of; in consequence, this matter was again taken into consideration in 1733, and a new table of dimensions formed, which, although it did not receive, like that in 1719, the sanction of the king in council, was followed in the ships built after this period. By the table in question, the first-rates remained of the same dimensions as heretofore: the length of the other classes were the same, but they received a considerable increase in breadth. Although the first-rates were not enlarged, their stability was augmented, and their sea-going properties improved, by a discontinuance, shortly after this period, of an apartment raised above the poop, at present placed abaft in ships of the line, and which was then called the poop-royal.

In 1741, another table was formed for the dimensions of ships, which gave to them an increase both in length and breadth: this was in force until 1745, when, from complaints of want of size to carry the guns established in 1743, and also of the insufficiency in the scantlings of the timbers of English ships, compared with those of foreign nations, the government ordered that some of the flag-officers of the fleet, the Surveyor of the Navy, and the several masters shipwright of the dockyards, should consult together, construct draughts, and form tables of the principal dimensions, scantlings, and masts and yards, for a ship of each class, which should be followed for the future. The tables so formed were ordered to be carried into effect in 1745, and fortunately were the last which were enforced for the purpose of limiting that which must necessarily change, according to the circumstances of the times, the practice of other countries, and the progress of knowledge. The ships built by these draughts and scantlings had, when compared with those formerly constructed, a considerable degree of stability: they carried their ports high, and were found to be strong and useful vessels; but it was soon discovered that they were wanting in the property of velocity: this was imputed to their being too full in their bows and sterns. To remedy this, it was ordered, in the year 1756, that the draughts should be altered in the fore and after bodies, and the dimensions increased, to retain sufficient displacement. In this reign it was

determined that no more 80-gun ships with three decks should be built, as they were too small to compete with the three-decked ships of other nations. The Newark, launched in 1747, was the last of this class; and for the same reason (in 1756), the ships of 60 and 50 guns were no longer considered as belonging to the ships of the line.

At the demise of George II., it was found that the navy had been doubled, during his reign, in its real force.

At the accession of George III., the establishments of 1745 were abandoned altogether, and a considerable increase took place in the dimensions of all classes of ships. A first-rate, by the establishment aforementioned, was to measure 178 feet in length and 51 feet in breadth; the Victory, launched in 1765, measured 186 feet in length and 52 feet in breadth: and, although small compared with ships of the same class of the present day, she has been considered, from that period to this time, as an excellent ship.

The naval warfare which was constantly carrying on during the early part of this reign, induced a more than ordinary attention to the fleet; and to this circumstance may be attributed the improved size and form of the ships which composed the navy at the close of the American war.

In 1783, it was determined to copper sheath all ships: when an important change took place, that of substituting copper bolts as fastenings for the bottom, and copper connecting hinges for the rother, called pintles and braces, instead of iron, hitherto used for these purposes. Copper sheathing for ships' bottoms had been partially introduced in the year 1759, and more generally practised in the succeeding years; and notwithstanding all the precautions which were taken to protect the iron bolts and rother irons, they became very soon oxidated, and it is to be apprehended that some ships foundered therefrom. The oxidation of the iron was attributed, at this time, to its being "a less pure metal than copper;" for it remained for the master mind of a Davy to discover the physical law, that "when two dissimilar metals are in contact, and also with sea-water, a voltaic effect is produced, which occasions a rapid corrosion of the more oxidable metal," while the other remains perfect. I have great satisfaction in having the opportunity of mentioning

this circumstance in a place where this brilliant discovery was made, which was alike honourable to the talents of our eminent philosopher, as it is creditable to the members of this Institution, who afforded the means of his experimenting, by their excellent and extensive apparatus.

At the return of the fleet into ordinary, at the several ports, in 1783, a general survey took place, to ascertain the state of the several ships: those which were old, and from other causes considered unserviceable, were either sold or taken to pieces, and those in a state to be repaired were put into good condition for future service. The wishes of His late Majesty, to have at this time a numerous and well-conditioned fleet, were ably carried into effect by the talents and exertions of Sir Charles Middleton (afterwards Lord Barham), the then Comptroller of the Navy, and Mr. Henslow (afterwards Sir John Henslow), the Surveyor. To the politic views of George III., to the liberality of the Parliament in voting money, and to the exertions of those civil officers whom I have named, we owe the numerous and well-conditioned fleet, which enabled our naval heroes to combat and prevail over the gigantic force which France possessed at the early period of the Revolutionary war.

The importance of giving the ships a greater proportionate length to breadth, in order to improve their sailing qualities, became the subject of inquiry. In consequence, the Prince, of 98 guns, was cut asunder in the middle, the ends drawn apart, and an additional length (eleven feet) given to her midship capacity. The Hibernia, of 120 guns, and Ocean, of 110 guns, then ordered to be built, were also lengthened eleven feet. Yet these ships, when so altered, were very inferior in dimensions and capacity to the Commerce de Marseilles, of 120 guns, which was brought from Toulon, as a prize, about this period.

In 1793, it was considered necessary to appoint an additional Surveyor of the Navy; and the choice of the government fell upon Mr. Rule (afterwards Sir William Rule), who—and I speak from long personal knowledge—possessed a strong mind, a clear perception, and was second to no man in England in a knowledge of his profession, in zeal for the public service, in industry, and in mental and bodily activity. To him was en-

trusted the construction of the draught of a first-rate ship of war of 120 guns, which should rival those of the French and Spaniards; and he accordingly produced that of the Caledonia, a ship 205 feet in length on the lower gun-deck, and 53 feet 8 inches in breadth, which has proved one of the most serviceable and efficient ships of her class in the known world, and still serves as a model for our first-rates. Like most men of genius, Sir William departed from the old beaten track, and formed a body having sufficient displacement for a first-rate, but approximating in form to that of a large frigate. This ship, contrary to the opinions which some persons formed, and indeed expressed at the time, answered so well, that she was the admiration of all English as well as foreign seamen, who witnessed her sailing and sea-going properties. But we owe not only the Caledonia, but the Bulwark and Repulse, of 74 guns, and many other excellent ships in the several classes, to the talents and knowledge of Sir William Rule.

Before this period, while individuals made use of steam engines and other powerful machines in their manufactories, our royal dock-yards depended almost, if not altogether, upon men and horses for pumping the docks, raising of weights, and other arduous labour. But this was to be an era in naval science. A nobleman was appointed by the king to conduct the naval administration of this country, who was initiated in scientific pursuits, and appreciated their influence in the useful arts. In consequence, the talents of Bentham, Brunel, Barrallier, and others of lesser note, were brought into action; our dock-yards were improved, the most powerful and most useful machines introduced, and some ships constructed upon scientific principles. The employment of these gentlemen for the public service had not only a direct, but an indirect, influence towards improvement of all kinds, as it caused others to think upon subjects which never before entered into their contemplation; and thus the minds of many of our officers were expanded. To whom, then, do we owe these and other advantages, which our navy and dock-yards have derived?—To a nobleman, to praise whom before the members of this Institution would be arrogance; as he is above all praise of mine, and as they are so well

acquainted with the splendid talents and private worth of their late President, Earl Spencer.

Our conquests at sea, during the late wars, put us in possession of some excellent foreign ships; for while the science of naval architecture was neglected during 150 years in this country, the French, the Spaniards, the Danes, and the Swedes, carried it to a considerable height; and it is only justice to say, that many of our improvements in the construction of ships' bodies are due to the mathematical knowledge and talents of rival nations: as a proof, all our second-rates, and also all the frigates of 46 guns now being built, are constructed, as far as form is concerned, after French models; and, notwithstanding the superiority maintained by us at sea, we have followed the practices of other nations, and not taken the lead, which we certainly ought to have done in this science. But not so with the practical construction of ships; for in this we have the merit of excelling all other countries. By substantial workmanship, our ships were enabled, during the late wars, to keep at sea the whole of the year, even in the most boisterous and inclement seasons, and, if I may be allowed the term, to hermetrically seal the ports of our enemies.

The consideration, however, of the workmanship on ships leads us naturally to the new system of carpentry, invented and introduced by Sir Robert Seppings in the year 1810, and first put in practice in His Majesty's ship Tremendous.

In order to elucidate the change of system in ship-building, and point out the advantages of the new over the old method, it will be necessary to explain the state in which it was before Sir Robert introduced his principle, which has not been inaptly termed "the diagonal system of ship-building."

The keel, which is the lowest timber, or an assemblage of timbers in a ship, runs in a longitudinal direction from head to stern. On the fore end of the keel are placed the stem, with the inner stem, and the knight heads; on the after end of the keel, the stern-post is secured: this post is that on which the rother hangs, and, for its greater strength and security, a piece of timber is brought on its fore side, called the inner post; crossing these, are larger pieces of timber lying horizontally,

called transoms; and on each side were placed, nearly vertically, the fashion pieces, which make the stern-frame complete. On the keel, in the fore and aft parts of the ship, pieces of wood are placed and fastened, called dead wood: these are more or less, in dimensions and number, as the bodies of the ships are more or less acute at those places. Crossing the keel and the dead wood, large pieces of timber are let on and fastened: these are called floors. To them are attached the frames or ribs, which are an assemblage of timbers, forming two bends, composed of futtocks and top-timbers, which were united at their heads and heels with angular chocks. Between each pair of frames other timbers were placed, corresponding to the frame-timbers, but as they were not united into frame-bends, they were denominated filling-timbers; the interstices left between the floors were then filled up by large pieces of timber, corresponding to them in some degree, called cross chocks; the frames and fillings were then filled in, or made solid, as high as the floor-heads only. The vertical frames being placed, and accommodated to the intended form of the ship, and the floors secured by the internal keel, or, as it is called, keelson, the planking, laid horizontally, is then brought on outside, the beams of the several decks put in their respective places, the inside planking worked, and the beams secured to it and to the frame by wooden, hanging, and lodging knees. In this stage of the description, I wish to direct your attention particularly to the inside horizontal planking in the hold, called footwayling, and to the bends of massive timbers, called riders, put over it; as the omission of these, and the substitution of another arrangement of timbers, form a principal feature in the new mode of ship-building. It will be perceived by the models now before us, and by the description which I have given, that the materials were, in the old method of ship-building, laid at right angles to each other; indeed, all of them were so placed, with the exception of the breadth and top riders put to strengthen their top-sides, which were laid in a diagonal direction; and by the intervention of the internal and external planking, no air could circulate through the interstices between the frames, but, on the contrary, was kept there in a stagnant state, to the great injury of the timbers. And the sides were also

encumbered, and the fighting and training of the guns impeded, by the wooden knees, and breadth, and top riders.

The imperfections of this method of construction were shown immediately after the ships were launched, and to a great and often alarming degree when they had been some years in service: first, by arching or hogging,—that is, by the fore and after bodies dropping, and the middle rising in a longitudinal direction, or, in other words, by the ship assuming a curved, instead of preserving a straight, line; secondly, by that of sagging,—an alteration in figure, generally brought about by the force which the main-mast discharged upon a point, having there a tendency to press the floors outward; and the third, by the separation of the parts composing a ship, by the tendency which the beams have to pull in the one side and force out the other, when she lies over under a press of sail, or from the motions of rolling.

To remedy these evils, it was not only necessary to make another disposition and distribution of most of the materials, but also to bring about a better combination of the parts, so that their strength should not be partially applied, but generally diffused, to meet those shocks to which ships are subjected in an agitated sea, or if they should be accidentally driven ashore; or to give what is so desirable in architectural works, a maximum of strength with a minimum of materials.

Let us now see by what means, and how far, Sir Robert Seppings has effected these objects.

The first improvement which strikes our attention is, that, instead of the cumbrous pieces of wood formerly used for the floors (which were often difficult to procure, even for one ship, in an extensive forest,) they are now formed of three pieces of timber, of much smaller dimensions. Two of these, called half floors, abut on the keel, and their ends are united by a circular coak, as are the ends of all the frame timbers in this mode of ship-building. The joints of these two pieces, so united, are strengthened by a third piece, called a cross piece; which unites them firmly, if not immoveably, by its being coaked and bolted to their sides. The angle chocks, formerly placed at the heads and heels of the timbers (which, for nearly a century, were peculiar to the English ship-builder) are now discontinued,

and each timber has a flat abutment. And in order to reduce the curvature of the several pieces, they are of a less length, and, consequently, the frame bends are procured with less difficulty, being composed of a greater number of pieces. All the timbers are regularly formed and fastened into bends, instead of being alternately frames and fillings, as before mentioned. The transoms and fashion-pieces are discontinued in the stern, and this part of the ship is timbered in a similar manner to the bow, and, when finished, is termed the circular stern. When the frame is completed, it is filled in, or made solid to within four inches of the position of the underside of the plank placed next the orlop clamps. Two additional keelsons are worked inside, parallel with the keelson: these extend about 35 feet in midships, in ships of the line; upon these the step of the main-mast rests.

We now come to an important novelty in this mode of construction: I mean the diagonal framing in the hold, usually called the trussed frame. This framing is composed of riders, longitudinal pieces, and trusses. The riders are timbers which lie diagonally on the inside of the frames, with their upper extremities under the gun-deck shelf, and extending from thence to within six inches of the limber strake: they commence at the shelf-piece amidships, and lie at opposite inclinations in the fore and after bodies, of 45° below a horizontal line, and are united to the timbers of the ship's frame by coaks and bolts. The longitudinal pieces are then placed between them, and are put over the joints of the timbers: thus they perform the double office of strengthening the frame-bends at their weakest parts, and preventing the riders from moving. The riders and longitudinal pieces so placed, it will be perceived, form rhomboids; the trusses are then fastened in a diagonal direction, within those rhomboids, and thus form a series of triangles. Instead of longitudinal strakes, diagonal pieces are put between the ports: these are placed in the same direction as the trusses in the hold.

The next point for attention is, the connexion of the beams to the sides of the ships. The beam-ends rest upon clamps and shelf-pieces, and they are coaked to the latter. These shelf-pieces or internal hoops do the office, but more effectually, of

the lodging-knees in the old method of ship-building. Under them, at those places where the beams rest, chocks are placed, not only to give them support, but also to allow of an iron knee being bolted upon the face of these chocks; two arms, from this knee, clasp the sides of the beams. These are in lieu of the hanging knees of wood. It is but justice to remark, that the great advantages which naval architecture has derived from the introduction of shelf-pieces, is due to the ingenuity of the French.

For the better security of the beams, thick waterways are placed upon them: these are also coaked and bolted through the sides of the ships; and on the decks, next the waterways, a thick strake is let into the beams, called a side-binding strake. Between each beam a half-beam is introduced, which is a substitute for carlines and ledges formerly placed there; and the flooring, or flat of the deck, is laid diagonally upon them.

It is obvious to every one who examines the model, that those admirable securities, the shelf-pieces, being cut off at the stern, render this part very weak in comparison to the bow and sides of the ships. To remedy this, Sir Robert Seppings introduced the circular stern, which, as I have before shown, is timbered in a similar manner to the bow; the shelves now run round, and act as internal hoops. This stern also affords superior means of offence and defence.

Such are the principal features of this new mode of ship-building, which, notwithstanding the prejudices which act against the introduction of any innovation, is now adopted by most, if not all, European nations.

It has been remarked, that imperfections in the structure of ships allow the body to arch, to sag, and to separate side from side. Let us see, then, how far Sir Robert Seppings' method of ship-building goes to remedy these defects.

To prevent the arching or bending of the ship in the direction of its length:—First, the filling in of the frame alone increases in a great degree, the resistance to compression; secondly, the diagonal framing, placed to oppose this action, is a combination of two systems of resistance, either of which is, in principle, perfect: the one consists of the series of timbers called riders, lying at an angle of 45° from a vertical line, which may be supposed to pass through the neutral axis of the ship, to a

horizontal line at the keelson; and not only forms a series of ties to prevent extension, but, by crossing all the horizontal ranges of the outside planking and the vertical ranges of the timbers of the frame, forms, in conjunction with them, a series of triangles to resist any alteration of form in the structure. The other system consists of a series of timbers, which also form an angle of 45° with the afore-mentioned vertical line, and are at right angles to the former: this system is composed of the range of trusses or struts, which act by their resistance to compression, and may therefore be in short lengths; and, as they are placed between the different members of the former system, by the combination of the two, no alteration can take place in the fabric of the ship, which will not be opposed, both by the resistance to extension of the fibres of the materials which compose the one, and by the resistance to compression of those composing the other. In addition, there is a third series of timbers, which lie horizontally, and are the diagonals to the parallelograms formed by the intersection of the two systems of ties and struts. This series of timbers, in conjunction with the former two, completes a third system of resistance, by forming a combination of that unalterable figure the triangle.

It may possibly appear to some, from this explanation, that there is a greater combination in the diagonal system than is necessary; but it must be remembered, that although the two systems which compose the whole are each perfect in principle, yet much allowance must always be made, in practical applications, for unavoidable imperfections in materials and workmanship; and it is on this account that it becomes necessary, in order to draw the greatest possible advantage from the use of either of these systems, to perfect its several parts as much as possible, by combining each with the other. Thus the ties, while they make the connexion between the several parts of the fabric more complete, not only increase and more equally diffuse the strength which is derived from the abutments of the trusses, but they also make those abutments more perfect. And again, the struts, by taking away a great portion of the strain, which would, without their intervention, be brought upon the fastenings of the ties, permit the fabric to derive the maximum

of the advantage resulting from the non-extension of those timbers.

Such are the advantages of the diagonal trussed frame, in preventing an alteration of form in a longitudinal direction. In addition, the shelf-pieces and thick waterways worked at each deck, and the abutment and truss-pieces placed between the ports, offer also considerable resistance to the extension of the body of the ship.

Sagging is prevented by the two additional keelsons worked in the middle of the ship, upon which the outer ends of the step for the main-mast rest. These keelsons distribute, over a space of about 35 feet in length, the immense weight and strain of the main-mast, with all its appendages; which, but for these, would be discharged upon one point. And as the floors where the keelsons are placed lie in nearly a horizontal position, by their uniting these floors and giving uniform strength at this part, they prevent any movement in the fabric of the ship, from the upward pressure which the water exerts.

The separation of one side of the ship from the other, is prevented by the union of all the beams by shelf-pieces, thick waterways, and side-binding strakes, and the connexion again of these with the sides of the ships; so that any strain or force exerted upon a part is resisted by the strength of the whole body. The beams are further tied down by their being united to the chocks with iron clasp knees.

Having stated the advantages of this method, in giving strength to ships, let us now examine how far it tends to their durability, and to the comfort of their crews.

In the first place, strength or immobility tends, in itself, to give durability; for if the materials begin to move upon the fastenings, the ships leak, decay of the wood commences, and a general disunion of the parts follows.

It has been observed in all times, that both when wood is excluded from the air, and when there is a free circulation of air, it shows little tendency to decomposition. In the mode of ship-building now under consideration, advantages are taken of these facts; for we find that where air will not freely circulate, at the bottom, there the ships are made solid with wood and cement: but, "to make assurance double sure,"

when the ships are completed, a mixture formed of tar and carbonate of lime is forced into the frame, by a pump of sufficient power to fill all interstices left by the imperfection of workmanship, and, being an insoluble substance, preserves the timber from the action of water upon its surface. Again, above water, where a circulation of pure air can be easily effected, we find that this is brought about by the spaces between the timbers of the frame and their communication with the openings just above the range of the shelf-pieces, which allow the air to circulate freely from deck to deck, thus preserving the timbers of the ships and the health of their crews. The advantages of this arrangement are only to be fully appreciated by those who have experienced the inconveniences which formerly arose to the people, when the hammocks were down and the port-lids barred in, and the comparative comfort produced by the present system.

The friendship which has long subsisted between Sir Robert Seppings and myself, and the high esteem in which he is held by all who know him, make me hesitate in giving an opinion on the advantages which this country has derived from his talents. Allow me, then, on this point, to address you in the words of the Committee of the House of Commons on Finance, in the year 1819, and to which I fully subscribe :—

" Your Committee deem it their particular duty to notice Mr. Seppings, one of the Surveyors of the Navy, to whose abilities and exertions this country is mainly indebted for many of its most valuable improvements in naval architecture ; the ingenious models of which have been submitted to the inspection of your Committee, with all the necessary explanations of their several uses and application. Your Committee do not pretend to describe or appreciate, with accuracy, the value of these improvements ; to estimate which, to their full extent, requires considerable professional experience. They are, however, fully convinced that the result of them will be to effectuate, in the construction of ships of war, a great saving of expenditure to the public, and to secure a proportionate economy of human life, arising from the superior durability and greater power of resistance to the elements, and to the casualties incidental to nautical life, which the modern system of

keeping our fleets at sea, at all seasons and in all weather, has rendered of the utmost importance. These services, although they have nothing of that brilliancy which forcibly attracts public admiration, will continue to confer a lasting benefit on the British nation, long after that period when the beneficial effects of victories, however splendid, shall have passed away."

As I have mentioned, as a collateral circumstance, the establishment of the several dock-yards at the time each took place, I must not omit to state, that in the year 1813 an additional naval arsenal was commenced at Pembroke, in South Wales.

We have hitherto, in size, followed the practices of other nations; and as our neighbours, the French, have lately given increased dimensions, not only to their three-decked ships, but also to those of the other classes, adhering, in a measure, to the practice of America, it is probable that we shall be obliged, at no distant period, to follow this example. With respect to the first-rates now building in France, which are said to be 232 feet in length and 60 feet in breadth, these dimensions appear to me to be carried to the utmost extent, if not beyond the limits of propriety; for nature does not furnish, in any number, trees sufficiently large for their top-masts, nor men sufficiently powerful to take in their sails, according to the present practices: nor is the depth of water, in some of the harbours on the coasts of England and of France, sufficient for their safe reception. Such ships, then, appear to be rather monuments of the riches and splendour of a nation, than machines of usefulness.

In conclusion,—I have had occasion to mention before the name of Chapman, in the highest terms of praise, as a man of genius and knowledge, who combined in a more eminent degree the theory and practice of naval architecture, than any other person. The opinion, then, of so able a constructor, with respect to the difficulties which attend the naval architect, will be received with some degree of deference.

Chapman says, "To possess the theory of naval architecture seems to exceed the force of the human understanding: we are obliged, therefore, to content ourselves with a part of this vast science; that is, with knowing sufficient of it to give to ships the principal good qualities," but "of these qualities one is at variance with another: it is therefore necessary to try so to

unite theory and practice, that no more is lost in one object than is necessary to secure another; so that the sum of both may be a maximum."

To whom, then, are we to look for improving, not to say perfecting, our ships? Is it to the men who may bring forward some geometrical or mechanical series of curved lines for a ship's body, deduced from one or more curves? for this has been many times done, and may at all times be performed by the mere dabbler in the art;—or to those, who, regardless of any rules, build ships by what they call the eye? for there are enough of these. And when either are asked for reasons for any particular construction, they assume mysticism, and would "appear wise by saying nothing." Certainly, from no such men are we to hope for improvement in a science pregnant with difficulties, to surmount which "seems to exceed the force of the human understanding." But let us look for the advancement of naval architecture, to those who unite the theory with the practice, who are patient observers of the physical facts which experience brings to their view, and have sufficient science to account for these, either by laws long established, or, if not, to endeavour to discover new ones. For what is theory, in its legitimate sense, but a law, or system of laws, established and confirmed by a series of well-conducted experiments?

Naval architecture and naval tactics have derived their greatest advantages and improvements from men of science, and not from mere practicians. To Bouguer we are indebted for the 'Traite du Navire,' and to Euler for the 'Theorie complette de la Construction, et de la Mæneuvre des Vaisseaux,'—works of the highest merit. Pére le Hoste and Clerke were clergymen, yet their works are consulted upon all occasions by naval tacticians; to the latter, Rodney and Nelson owe immortality, by performing a new evolution laid down by him; that of breaking through the line of battle formed by the enemy. The mariner's compass, by Gioja, and the highly useful instrument, its correcting plate, by Barlow, we owe to mathematicians. In fine, the application of lunar observations, by Maskelyn, the quadrant of Hadley, and the chronometers of Harrison, were the productions of scientific men.

It may here be remarked, that the politic views of Earl

Spencer, to which I have before alluded, in introducing scientific men into our dock-yards, were adopted on a more extensive scale by the government in the year 1810, who established a school at Portsmouth for the education of naval architects, on a scientific plan; so as to embrace all the advantages of a similar establishment introduced into France, in 1752, by M. Rouillé, then *Ministre de la Marine*, and unite with them a more extensive knowledge of the practice of ship-building.

The hopes and expectations of this country, for improving our ships of war and perfecting naval science, are naturally centred in those gentlemen who have received so liberal an education, and one so fitted to this purpose; and having a knowledge of most, if not all, of those who have been educated at this establishment, I am happy to give my opinion that the expectations so naturally excited will, at no distant period, be realized.

Whoever consults the history of this country, with the view of ascertaining the means by which she arrived at her present greatness, may trace the general fact, that she has risen or fallen in the scale of nations as her navy has been fostered or neglected. Upon the navy, then, the honour, the safety, and the best interests of Great Britain depend; and we may rest assured that this service will be protected by the Prince who now wields its destinies, and who has been a sharer in its honours and in its perils.

It must be received, by all who now hear me, as a most gratifying circumstance (and I make the assertion not from hearsay, but from an intimate knowledge of the fact,) that, at no period of our naval history, did this country possess a better-conditioned fleet than at the present time. And further, let me impress upon your attention, that the navy is not only our surest defence, but the means to wealth and national prosperity; to ensure which, our ships should be numerous, be in all good properties fully equal to those of our enemies, be preserved with unceasing care, and be commanded and navigated by the valiant, adventurous, and hardy sons of the United Kingdoms.

Art. X.—*Remarks on the Stability of Ships; with Notice of a Memoir entitled* 'Applications de Geometrie et de Mechanique, à la Stabilité des corps flottants;' *Par Charles Dupin, Membre de l'Institut de France, Academie des Sciences, &c. &c.*

The stability of floating bodies, with its application to ships, has been successfully treated by many writers. In the essential parts of the subject, whether treated geometrically or analytically, all have founded their investigations on the same established principles of mechanics. Although experiment has determined many facts connected with the action of ships at sea, which, probably, mathematical science would never have discovered, yet, on the other hand, many of the most important properties of ships, have been explained and rendered capable of being correctly measured, by the discovery of principles deduced from the laws of mechanics, which could never have been ascertained by mere experiment and practice. The stability of ships is one of the qualities deducible from the laws of mechanics, independently of experiment. Experience is necessary only in the determination of the degree of stability to be given to any ship, the design of which is to be made, by comparing it with the degrees of stability which ships of a similar kind, of known character, are found by calculation to possess.

The oldest work known, on the subject of floating bodies, was written by Archimedes; a commentary was written on it by Rev. Abram Robertson, contained in the Appendix to the Latin edition of the works of this ancient philosopher. The demonstrations in this work, which are conducted synthetically, determine the conditions of equilibrium of spherical, cylindrical, and parabolic bodies. The general investigation of the subject was left to modern times. Nineteen centuries afterwards, the subject was again resumed, and rendered more general by Bouguer in his *Traite du Navire,* and by Euler in his *Scientia Navalis,* and in his *Theorie complette de la Construction des Vaisseaux.* In the works of these two authors, the investigations are restricted to the cases of symmetrical forms with

respect to a plane: circumstances which by no means affect their application to ships, which are generally considered as necessarily symmetrical. Euler investigated the subject analytically, Bouguer geometrically, the method which has been most commonly adopted by writers on naval architecture. In this country, the subject of floating bodies has been treated very ably by Atwood, in a paper in the Philosophical Transactions of the Royal Society in 1796, and was afterwards very usefully applied by him to ships, in a paper in the same Transactions for 1798, capable of general use in the practice of construction.[1] The circumstances in which the application of Atwood's method to practice differs from those of Bouguer, are shown in ART. X., Vol. I., of this work.

The Memoir of M. Dupin, on the stability of floating bodies, is the first application of the method given by him in five other memoirs of geometry, under the title of '*Developpements de Geometrie,*' to follow the descriptive and analytical geometry of M. Monge. The investigations in this Memoir are very elegant, and it contains much which is new on the subject.

The stability of floating bodies is of two sorts: hydrostatical stability, the stability of a floating body at rest; and hydrodynamical stability, the stability of a floating body in motion.

Most treatises on the stability of ships relate chiefly to the hydrostatical stability. The hydrodynamical stability is attended with great difficulties: its dependence on the resistance of fluids, one of the subjects the least known of any in mechanics, renders it impossible to do more, than approximate to the correct determination of its value under the circumstances of a ship under sail. Enough, however, is known on the subject of stability generally, to render its application to ship-building sufficiently correct for the practice of design; at least as far as relates to the safety and general efficiency of a ship. The relative stability of ships is generally compared only in relation to their hydrostatical stability; so that, in fact, it is merely the relative stability of ships at rest, which is compared together. When the ships are in motion, the ratio of their stability is

[1] The principles in Atwood's paper are concisely generalised in a paper on the stability of ships, written by Mr. Read, in the 'Essays and Gleanings of Naval Architecture.'

altered; and it is desirable to consider, as far as our knowledge permits us, the effect of the different forces which act on the ships when under sail. If we assumed any one of the theories of the resistance of fluids, which have been applied to ships as correct, a theory of stability, embracing all the circumstances of a ship under sail, might be formed. What the effect of such a theory of stability might be on the design of ships, we cannot, with our present knowledge of the subject, determine.

In considering the hydrostatical stability of a ship, the ship is supposed to be at rest; and the disturbing or inclining force must never, in this case, be external: for every external force must cause motion, which will bring into action other forces. The equilibrium of hydrostatical stability is always produced by the weight of the ship and the vertical pressure of the water upwards.

When a ship is under sail, the equilibrium of hydrodynamical stability is produced by four forces: the weight of the ship, the vertical pressure of the water, the wind on the sails and on the part of the ship above the water, and the resistance of the water caused by the motion of the ship. To the latter force might also be added the resistance of the air, caused by the motion of the ship, on the part of the ship above the water.

The weight of the ship is a constant quantity, which may be always estimated as acting through a vertical line passing through its centre of gravity.

The vertical pressure of the water, when a ship is deflected from its upright position, acts either to restore it to its upright position or to incline it further, by causing it to revolve round a horizontal axis passing through its centre of gravity. In the equilibrium of hydrostatical stability, the vertical pressure, which is equal to the weight of the ship, acts always through the centre of gravity of the displacement. When a ship is in motion, the vertical pressure of the water on any elementary part of the surface of the body below the water, is diminished (see ART. XX., Vol. 1.) in relation to the velocity and the direction of the motion. The vertical pressure of the water is not, as in the case of a ship at rest, equal to the weight of the whole volume of water displaced by the ship; as the ship in motion, considered merely in relation to the principle just mentioned,

sinks deeper in the water than when at rest. The value of the vertical pressure is determined in relation to the ship's velocity and the direction of its motion. The mean direction of this vertical pressure, also, no longer necessarily passes through the centre of gravity of the displacement, as when the ship is at rest, but depends on the form of the body, and the direction and velocity of the ship's motion. It probably does not pass far from this point, though the true direction in which it passes is one of the circumstances which influence, although not practically of great importance, the hydrodynamical stability of the ship.

When a ship is moved from a state of rest, by the force of the wind on the sails, the resistance of the water gradually increases, while the relative force of the wind gradually diminishes, until the ship has attained its greatest velocity; when the horizontal effort of the force of the wind on the sails, and the resistance of the water on the ship's body, become equal. The mean direction depends on the form of the ship's body; when the ship begins to move in the water, the force of the mean resistance gradually increasing, and the relative force of the wind gradually diminishing, two lines being taken to represent the direction and value of these forces, and the parallelogram being completed, the diagonal represents the resultant of these forces. The locus of the extremities of different diagonals representing the resultants of these forces, at consecutive periods during the time occupied in the ship's obtaining its greatest velocity, is evidently a parabola, having the direction of the mean resistance of the water, and the direction of the force of the wind, as tangents.

When a ship moves in a direct course, the mean direction of the water rises considerably, and the direction of the force of the wind rises a little above a horizontal line, more or less, according to the rake of the masts aft. These two forces are equal only in a horizontal direction; by the composition and resolution of these forces, a vertical force results, which therefore necessarily raises the ship, so that it will not sink, on this account, so deep in the water as when at rest. The quantity the displacement will be diminished, may be easily ascertained when the direction of the mean resistance of the water is known.

Suppose the area of the sails struck perpendicularly, by the force of the wind, to be 19000 square feet, and that, by means of an anemometer (an instrument for measuring the force of the wind), the force of the wind on a square foot is found, in the case under consideration, to be 3 pounds; then, 57000 lbs. is the total force of the wind on the sails. The directions of the sides of the triangle of forces being known, the angles of the triangle are known, and one of the sides representing the force of the wind being known, the other sides may be immediately found. Let the angle made by the mean direction of the water, and the direction of the force of the wind, be 36 degrees, and the angle opposite to the direction of the wind, 58 degrees; then the side of the triangle representing the vertical pressure, will be 39596 lbs., or 17.6 tons. This quantity, by which the displacement would be diminished, will evidently be greater in proportion to the velocity of the ship, and to the greater elevation of the mean direction of the water. If the direction of the mean resistance were very high, the quantity by which the ship would be raised out of the water might be equal to, or even greater than, the whole force of the wind.

In order that the force of the wind on the sails and the hull of the ship, and the mean direction of the water, may balance, so that the ship may sail without sinking deeper at either of the extremities, and rising at the opposite extremity, it is necessary that the centre of effort of the wind may be at such a height, that the force of the wind multiplied into the perpendicular distance of its direction passing through the centre of effort of the wind, from the centre of gravity of the ship, may be equal to the force of the mean resistance of the water, multiplied into the perpendicular distance of its direction from the centre of gravity of the ship. If the centre of effort be above this height, the ship will sink deeper by the head, and rise at the stern; and if below this height, the ship will sink deeper by the stern, and rise forward. The distance the extremity of the ship will sink, will depend on the stability of the ship in the direction perpendicular to the axis of revolution. The equilibrium is established, when the moment of the vertical pressure of the water is equal to the difference between the moments of

the force of the wind and of the force of the mean resistance of the water: the moments being estimated, in this case, from the transverse axis of revolution.

When a ship moves in an oblique course, the same forces constitute the equilibrium as when moving directly, only differing in direction and quantity. The force of the wind and the resistance of the water are equal, only when estimated in a horizontal direction, in the oblique as well as in the direct course. The mean direction of the water in the oblique course rises much less than in the direct course, frequently passing but little above the centre of gravity of the ship; so that the moment of the force of the wind on the sails, being much greater than the moment of the mean direction of the water, the ship will necessarily incline on the lee-side; and the equilibrium will be established as in the direct course, when the moment of the vertical pressure of the water is equal to the difference of the moments of the wind and of the resistance of the water.

The mean resultant of the force of the wind, and of the resistance of the water, determines the quantity the ship will rise or sink bodily in the water, and may be estimated as for the direct course. The direction of the mean resistance of the water in an oblique course rising very little, and the force of the wind acting on the sails, which become inclined transversely, the vertical resultant of these forces is very small. Whether the resultant of these forces in an oblique course, for any particular case, gives a force in an upward or downward direction, can be known only by the actual determination of the mean direction of the water and of the force of the wind: these forces, in the general form of our ships of war at a moderate inclination, very nearly counterbalance each other, the resultant generally giving an upward force, which raises the ship a little out of the water. When the ship takes a sudden lurch by a heavy squall, the vertical resultant is diminished, sometimes destroyed, and probably sometimes changing its direction to a downward force; so that, as the heeling increases, the ship sinks deeper in the water, and as the ship returns to its upright position, the ship rises. The mean direction of the water depends on the rake of the stem and stern-post, and on the form of the body: the greater the

rake of the stem and stern-post, and the fuller the ship is at the water-line and immediately above, and the sharper below, the higher is the mean direction of the water, and the more will the ship be raised out of the water.

The hydrodynamical stability is certainly that which relates, most properly, to naval architecture; as it is under sail, that the stability of a ship is brought into action. Although the difficulties of the subject are so great, that, in the present state of the science, it cannot be correctly measured, yet an attention to the circumstances of the hydrodynamical stability, so far as relates to the general acquaintance with the elements on which it depends, will not be unattended with advantage in the design of ships. Fortunately, however, the effect of the elements on which the hydrostatical stability of floating bodies depends, forms so great a part of the measure of the hydrodynamical stability, that, for practical purposes, it will be found generally sufficient to compare together the hydrostatical stability of ships, in order to ensure this essential property in a proper degree.

One of the latest works on the hydrostatical stability of floating bodies, is a beautiful memoir by M. Dupin, to whose genius and zeal the marine affairs of France are extensively indebted.

In this memoir, M. Dupin, instead of considering the character of each state of equilibrium, by supposing the body to be inclined to infinitely small angles, determines at once all the positions of equilibrium, which any floating body of a constant weight and invariable form can take. He commences his investigation by proving some of the first principles on which the stability of floating bodies depends, and then rapidly passes to new and difficult considerations of the subject. He shows that, "in order that a solid floating body may be in equilibrium, not only is it necessary that the weight of the volume of the fluid displaced be equal to the weight of the body, but that the centre of gravity of this volume, and the centre of gravity of the body, be situated in the same vertical line." Suppose that all the planes of floatation of a floating body are determined according to this theorem, and that the centre of gravity of each of these volumes cut off by the planes of floatation is

determined; a surface passing through all these centres of gravity of displacement is contained within the body, and is *fermée.* This surface is denominated "*the surface of the centres of the displacement.*" All the planes of floatation envelop another surface, to which they are tangents, which is denominated *the surface of floatations.* By a geometrical consideration of the properties of these two surfaces, M. Dupin determines not only the known, but some new, theorems of floating bodies. A plane touching the surface of the centres of displacement at any centre, is parallel to the plane of floatation corresponding to that centre, and is therefore horizontal. In every state of equilibrium, therefore, a straight line, passing through the centre of gravity of the displacement, and the centre of gravity of the body, will be perpendicular to the surface of the centres of displacement. The determination of the positions of equilibrium of a floating body may then be determined, by ascertaining the perpendiculars to this surface, passing through the centre of gravity of the body. By means of these perpendiculars to the surface, the character of the equilibrium is immediately determined. If the perpendicular to the surface at any centre, when the body is inclined to a very small angle, passes above the centre of gravity of the body, the equilibrium is stable; if below, unstable: and if it passes through the centre of gravity of the body, the stability is indifferent. The intersection of the perpendicular to the surface, when the body is inclined, with the perpendicular to the surface when upright, is the point denominated the metacentre by Bouguer.

"Hence results this theorem, which appears worthy of remark: in comparing a position of equilibrium of a floating body with the neighbouring positions it can be made to take, the distance of its centre of gravity to the centre of its displacement is a maximum or minimum, according as the equilibrium is stable or unstable: in the equilibrium of indifference, this distance is constant."

By a consideration of the relation of these perpendiculars to the surface of the centres, it appears that, "for the direction which corresponds with the greatest stability of a floating body, the axis of rotation is parallel to the direction of the greatest curvature of the surface of the centres; and for the direction,

which corresponds with the least stability, this axis is parallel to the direction of the least curvature of the surface of the centres of displacement."

The surface of the centres of displacement is *fermée*, and the curvatures are throughout in the same direction. The centres of the mean curvatures are on the perpendicular, between the centres of the greatest and least curvature.

We see, then, that if the centre of gravity of the body is below the centre of the greatest curvature of the surface of the centres of displacement, at this position of equilibrium, the body will possess absolute stability in all directions. But if the centre of gravity of the body is above the centre of the greatest curvature, and below the centre of the least curvature, the equilibrium will be stable in the direction of the least curvature, but unstable in the direction of the greatest curvature. These two directions are at right angles to each other.

To determine the stability in all intermediate directions, M. Dupin has recourse to a curve, which he calls *la courbe indicatrice.* It is, in this case, the intersection of the surface of the centres of displacement by a plane drawn parallel to a plane touching the surface of the centres of displacement, and infinitely near to it, which therefore indicates the form of this surface in the immediate vicinity of the tangent plane. The two curvatures of the surface of the centres of displacement being in the same direction, its indicatrix is always an ellipse, whose axes are parallel to the directions of the greatest and least stability. The conjugate diameters of the indicatrix represent as many systems of conjugate tangents of the surface of the centres.

The degrees of the stability are proportional to the squares of the diameters of the indicatrix, in every direction of inclination of the body. The diameter of the indicatrix in any section perpendicular to the surface of the centres passing through the centre of gravity of the body, regarded as the centre of curvature of the perpendicular section, is determined by this proportion: the square of the great or little axis is to the square of the diameter sought, as the greatest or least radius of curvature of the surface at the centre of displacement, is to the radius represented by the distance of the centre of gravity of

the body to the same point. This diameter being determined, two perpendicular sections are known, symmetrically placed in relation to the directions of the greatest and least stability. M. Dupin establishes this general theorem :—"In the equilibrium of a floating body, and terminated by any surface (regular or irregular), the stability considered in the different directions in which the equilibrium is disturbed, is always symmetrical with relation to two vertical planes perpendicular to each other."

The sum of the two conjugate stabilities, for the same position of equilibrium, is always constant, and equal to the sum of the greatest and least stability of the floating body.

These two planes intersect in the vertical, passing through the centre of gravity of the floating body, and the centre of gravity of displacement. These planes in ships are, evidently, the longitudinal and transverse planes passing through the centre of gravity of the ship and the centre of gravity of its displacement.

"In the general case, that is, with any form of the floating body, these principal directions being no longer indicated *à priori*, they must be sought for by reference to the surface of the centres of displacement. It is then sufficient to determine, on this surface, the directions of the two principal curvatures which cross each other at right angles at the centre of the displacement, to which the position of equilibrium under consideration belongs. These directions, as we have seen, will be precisely those of the greatest and least stability. We have occasion, in order to arrive at this, to bring into consideration the planes of floatation and the graphical magnitudes, which depend thereon."

The surface of the floatations is *fermée*, and has its curvatures turned in the same direction, like the surface of the centres of the displacements. These two surfaces never cross each other, the one always enveloping the other. "The surface enveloped by the planes of floatation, contains the centres of gravity of the areas of all these planes; the area being terminated, on all parts, by the exterior surface of the floating body."

When the body inclines to an infinitely small angle, the small volume immersed by the inclination, which is necessarily equal to the small volume emerged thereby, divided by the tan-

gent of the angle of inclination, is equal to the sum of the moments of the part of the plane of floatation, taken from the axis passing through the centres of gravity of these planes of floatation; and the simple moment of this volume, divided by the tangent of the angle of inclination, is equal to the moment of inertia of the area of the part of the plane of floatation, taking the same axis as the axis of the moments.

But the moments of the immersed and emerged volumes, divided by the tangent of the angle of the inclination, and by the volume of the displacement, are equal, together, to the radius of the arc traced by the motion of the centre of gravity of displacement. The radius of this arc is then equal to the moment of inertia of the total area of floatation, divided by the constant volume of displacement. The radius of curvature and this sum of the moments of inertia, being in a constant ratio to each other, they will be at the same time a *maximum* or *minimum*.

From which the following remarkable theorems result:—

1. "The greatest radius of curvature of the surface of the centres of the displacement is, for the centre under consideration, equal to the greatest moment of inertia of the area of the corresponding floatation, divided by the volume of the displacement."

2. "The least radius is, on the contrary, equal to the least of these moments, divided by the volume of the displacement."

3. "The direction of the greatest curvature of the surface of the centres of the displacement, is that of the axis of the greatest moment of inertia of the area of the floatation."

4. "The direction of the least curvature of the surface of the centres of the displacement, is that of the axis of the least moment of inertia of the area of the floatation."

"But the lines of the greatest and least stability of any surface cross each other at right angles. Then the principal axes of the greatest and least moments of inertia of the floatation cross each other at right angles, whatever be the figure of this area."

In general cases, it is evident that the vertical line passing through the centre of displacement will not pass through the intersection of two consecutive floatations. If the moments

are taken in relation to another plane, parallel to the plane passing through the vertical of the centre of displacement, the radius of curvature becomes identical with that determined in arriving at the results just obtained. The sum of the two moments must remain the same, when the plane to which the moments are referred is removed to any distance in the same direction. Their sum, multiplied by the constant mass of the weights acting in the two opposite directions, is precisely the total moment. As long as the centres of gravity of the body and of the displacement remain at the same height, the area of floatation may be removed to any distance, without any variation in the radius of curvature of the surface of the centres of displacement, for the position of equilibrium considered.

M. Dupin refers his consideration of the infinite transformations of the surface of the centres of displacement of different bodies, under the preceding limitations, to his examination of these transformations in his '*Developpements de Geometrie.*'

This general theorem results from the consideration, that, round a primitive centre of displacement, the curvature of the surface of the centres of displacement remains always the same, under all possible directions; and, consequently, that the primitive surface of the centres preserves a contact of the second order with every new surface of centres of displacement. The stability of the new floating body will then be equal, in all directions, to that of the first body.

M. Dupin then proceeds to determine the principal elements of the surface of floatations, on which the curvature of the surface of the centres of displacement depends. This surface, and the surface of the centres of displacement, which depend on each other, never cross, the one always circumscribing the other. The planes of floatation are tangents to the surface of floatations; and the point of contact of this surface with the area of each floatation is the centre of gravity of this plane, bounded by the perimeter of the floating body.

M. Dupin deduces the following results from his reasoning: "If a weight be applied to each point of the boundary of the floatation, proportional to the tangent of the angle which a vertical line forms at each point with the boundary of the floating body, the principal axis of the greatest and least moments

of inertia of their line of weights, will be respectively parallel to the lines of the least and greatest curvature of the surface of floatation;" and "that if the greatest or least moment of inertia of the boundary of the floatation, thus charged with weights, be divided by the area of floatation, the quotient will be the radius of the least or greatest curvature of the surface of the floatations."

After showing that the number of positions of equilibrium which a floating body can take, is equal to the number of perpendiculars which can be drawn to the surface of the centres of displacement, through the centre of gravity of the body; he proceeds to show, 1st, that "the total number of positions of equilibrium of a floating body, moveable round a fixed axis, is an even number;" and, 2dly, that "in the equilibrium of a floating body of any figure, and moveable round an axis of which the direction is invariable, the number of positions of equilibrium of stability is equal to the number of positions of equilibrium of instability. So that, in turning round the axis, it will pass alternately from a position of stability to one of instability."

To the author's proof of these theorems, as well as to Poisson's demonstration of the same principles by pure mechanics, M. Dupin shows that there is this objection: it is supposed that, in all the positions of equilibrium, the distances between the centres of gravity of displacement and the centre of gravity of the body, are either maxima or minima; but in the equilibriums of insensibility or indifference, this is not the case. He, however, establishes the correctness of the theorems, by considering the equilibrium of insensibility to be of a double character, as combining the equilibrium of stability with the equilibrium of instability; by which the objection is removed.

From the author's reasoning, there results also this theorem: that every floating body "can take, at least, one position of equilibrium of absolute stability, and one position of equilibrium of absolute instability."

This memoir evinces, throughout, great power in the author, of carrying forward the subject, from first principles to the most difficult investigations. Many of the theorems given in it were previously known, but there is also much that was not

known; and the investigation of the relation of many properties of floating bodies is altogether new, which opens the path to the consideration of many important parts of this interesting and important subject, hitherto unattempted.

The principles of the stability of ships are well known, and the methods of determining, by tedious calculations, the value of the stability at any angle of inclination, to a degree of accuracy fully sufficient for practice, are well understood by scientific constructors, who are in no danger of making a design which will be found deficient in this essential quality of a good ship. But there are still wanting easy and quick methods of estimating the relative degrees of stability of ships, by the comparison of measurements, which can be readily obtained. To such desiderata, the further investigation of the subject will probably quickly lead.

If it be asked, to what immediate practical benefit, in the design of British men of war, our knowledge of the stability of ships might be applied,—we answer, to the increase of the breadth of many classes of our navy; not by a rash and inscientific increase of this element, at the expense of other important qualities of a ship, but by the determination of its increase, founded on calculation and comparison.

Science dictates the further increase of this element, which experience, in many instances, has found highly advantageous.

Art. XI.—*On the Position of the Centre of Effort of the Sails, with respect to the Length of the Vessel; in reply to the Remarks inserted in* Art. XLI. *of 'Papers on Naval Architecture.'—By* Lieut. A. G. Carlsund, *of the Swedish Royal Naval Engineers.*

It was stated, in Art. XXXIII. of the 'Papers on Naval Architecture,' that "the common notion, that a full fore body carries the mean resistance further aft, is not true in general;" but this being thought evident to any one bestowing attention on the subject, the proof was not given: however, as it has

appeared doubtful to the writer of Art. XLI. of this publication, it may be proper to give it for the sake of illustration.

The demonstration given by Euler, in the work cited in Art. XXXIII., only proves that the mean resistance of a rectangle, moving in a fluid, is further aft than that of a rhomboid; but as this only happens because the foremost side of the rectangle has no effect towards turning the vessel, it may easily be inferred that the conclusion drawn from these two particular cases cannot be true in general. This will be clearly seen, if we suppose, instead of the rectangular body, one AD, (Fig. 19), rectangular before, and triangular behind the middle: in fact, the mean resistance in this figure is, according to Euler's mode of reasoning, in K, HK being drawn from the middle of BC and perpendicular to it, and the angle of leeway IFG being less than CDF. In the rhomboid EFCD it is in L, NL being drawn perpendicular to FC. Hence the fuller fore body EABC brings the mean resistance further forward than the sharper one EFC. This is then a case, which proves that the conclusions drawn by Euler are not true in general.

It will easily be seen that the mode of reasoning adopted by that eminent geometer, chiefly on purpose to make himself understood by the artists of those days, is not applicable for the wants of naval architecture, as it does not indicate the influence of different angles of incidence towards altering the forces which tend to turn the vessel: for which reason, the following method of calculating this influence will be given.

Suppose a surface AB, (Fig. 20), which will turn round a centre C, when acted upon by any force in the direction DP; CP is then the radius vector for the point P of the curve, and ACP the angular abscissa. DPM is the angle of incidence, PM being the tangent. Suppose the angle DPM $= u$, ACP $= \gamma$, PMC $= \beta$, CP $= z$. The force acting in the direction DP can be resolved into two: one parallel to the surface, and the other in the direction PG perpendicular to it; this latter, depending upon the force and upon the angle of incidence, may be represented by $f.(u).P$, or by $f.(u).ds$, when the shock is proportional to the surface, as is the case in fluids; ds being the differential of the curved line AB, and $f.(u)$ denoting any function of u. This force may again be resolved into GH perpen-

dicular to the radius vector CP, and HP in the same direction with PC: it is evident that, of these two forces, only the former tends to turn the surface, as the direction of the latter passes through the centre of motion. The angle HPM being = PCM + PMC, and HPG being the complement in a right angle to HPM, it follows that *sin.* HPG = *cos.* (PCM + PMC) = *cos.* $(\gamma + \beta)$; but GH, or the force which tends to turn the surface, is equal to PG . *sin.* HPG: it hence follows that this force is

$$= f.(u).ds.cos.\overline{\gamma + \beta}$$

and its momentum from the centre of motion C

$$= z.f.(u)\,ds.cos.\overline{\gamma + \beta}$$

The sum of these momenta, in every part of the surface, expresses the total momentum which tends to turn the surface: hence the larger this sum is, each moment being taken with its proper sign, the greater is the tendency to turn, or the ardency.

If Cp is another radius vector drawn near the former, and pn be drawn perpendicular to CP, we have P$n = dz$, dz being the differential of z, but P$n = p$. P . *cos.* MPH, or

$$ds = cos.\overline{\beta + \gamma} = dz.$$

this value being substituted in the above formula, and the integral taken, we have the total momentum:

$$= \int f.(u).z\,dz.$$

This expression was obtained in the supposition that the forces parallel to the surface, which represent the friction, have no effect to turn; and that the shock is in proportion to the surface exposed to it, and to some function of the angle of incidence. For bodies moving in fluids, the two latter suppositions are usually admitted; but of the former, there may be some doubt: it may, however, be remarked, that on the lee-side and the foremost part of the vessel, where the impulse is greatest, in consequence of the greater angles of incidence, the friction has a tendency to counteract the turning, which is greater in sharp vessels than in full ones, owing to the difference between their respective angles of incidence: hence it appears to follow, that the ardency calculated in this way will be proportionably

less in the fuller vessel than in the sharper one, than it would have been if the friction had been considered. As the laws for the resistance of fluids are not known, the exact measure of the ardency cannot be given; but from the above expression may be deduced, as far as the present state of the science admits of, that there is no reason why a full fore body should carry the centre of resistance further aft, or lessen the ardency, more than a sharp one.

If the resistance is considered proportional to the square of the angle of incidence, as usual, we have $f.(u) = sin.^2 u$; and when the vessel is symmetric with respect to the middle line, and the angle of lee-way MAK is $= \omega$, the value of u is on the lee-side $\omega + \beta$, and on the windward side $\omega - \beta = u$. C is the centre of gravity. The shock on each side of the middle line having a contrary action, the total momentum occasioned by the shock is

$$= \int (sin.\overline{\omega + \beta}^2 - sin.\overline{\beta - \omega}^2)\, z\, d z$$

$$= sin.\, 2\,\omega . \int . sin.\, 2\,\beta . z\, d\, z.$$

This formula expresses the effect of the shock, the integral being taken for all the parts receiving the shock. If the sides of the vessel are straight lines, then β is a constant quantity, and the momentum is

$$= sin.\, 2\,\omega . sin.\, 2\,\beta . \frac{z^2}{2}, \text{ or}$$

$$= sin.\, 2\,\omega . sin.\, 2\,\beta \left(\frac{a^2}{2} - \frac{b^2}{2}\right) \quad \text{- - (A);}$$

a and b being the limits between which the integral is taken. This latter expression belongs to a rhomboid (Fig. 21), where AB $= a$, AC $= b$, the angle ABC $= \beta$ and the angle of lee-way ω, any angle DBE, such that only the sides BC and BF receive the shock.

The formula (A) is applicable to any symmetrical body composed of straight lines, by introducing in it the value of β and the radie vectoris for the beginning and for the end of the line. It might even be applied to a curve, if the radie vectoris are taken so near each other that the portions of the curve between

them may be considered as straight lines. If the angle β is a known function of z, expressed by an equation, the momentum of the curve may be obtained by integration.

It may now be asked what function z ought to be of β, if the above expression of the ardency, or

$$\int . \sin . 2\beta z\, dz$$

should become a maximum or a minimum. If this expression be compared to $\int V\, dz$ or $\int f(2\, y\, dz)$, V becomes equal to $\sin . 2\beta . z$; and as, according to the known rules of the *Calcul de Variation*, $\frac{dV}{dy} = o$, it follows that

$$\frac{d . \sin . 2\beta . z}{dy} = o,$$

or $\cos . 2\beta . z = o$: hence $\cos . 2\beta = o$, and, consequently, 2β = a right angle, or $\beta = 45°$.

This is evidently a minimum, and it belongs to a square moving in the direction of one of the diagonals. In fact, it is easily seen that in this figure the ardency measured from the centre of gravity is $= o$.

If the expression $\int . \sin . 2\beta z\, dz$ is transferred to right angular ordinates x and y, we obtain

$$z = \sqrt{x^2 + y^2},\ dz = \frac{x\,dx + y\,dy}{\sqrt{x^2 + y^2}}$$

$$z\,dz = x\,dx + y\,dy$$

$$\sin . 2\beta = 2 \sin . \beta . \cos . \beta = \frac{2\,dx . dy}{dx^2 + dy^2}$$

$$\sin . 2\beta . z\,dz = \frac{2 . \left(x . \frac{dy}{dx} + y\frac{dy^2}{dx^2}\right)}{1 + \frac{dy^2}{dx^2}} . dx$$

$$= \frac{2 . xy' + yy'^2}{1 + y'^2} . dx$$

Supposing $\frac{dy}{dx} = y'$

In order to obtain, by means of the *Calcul de Variation*, the relation between y and y', by which this expression becomes a maximum, $\frac{xy' + yy'^2}{1 + y'^2}$ may be called V. If $\int V\,dx$ is to be a maximum, the variation or $\delta \int V\,dx = \int \delta V\,dx = o$; and the known rules of this sort of calculus give

$$\frac{dV}{dy}\,dx = d\,.\frac{dV}{dy'}$$

By taking the differential, we obtain

$$\frac{dV}{dy} = \frac{y'^2}{1 + y'^2}$$

$$\frac{dV}{dy'} = \frac{x\,(1 - y'^2) + 2y'.y}{(1 + y'^2)^2}$$

$$d\,.\frac{dV}{dy'} = d\,.\frac{x\,(1 - y'^2) + 2y'.y}{(1 + y'^2)^2}$$

$$= \frac{dx\,(1 - y'^2) + 2y'^2.dx}{(1 + y'^2)^2}$$

$$+ y''\,.\frac{(1 + y'^2).(2y - 2xy') - 4y'\,(x.\overline{1 - y'^2} + 2yy')}{(1 + y'^2)^3}$$

This expression is $= \frac{dV}{dy}\,.dx = \frac{y'^2}{1 + y'^2}\,.dx$: hence

$$(y'^2 - 1).(y'^2 + 1)^2 = 2y''.(y.\overline{1 - 3y'^2} - xy'\,\overline{3 - y'^2}),$$

and, consequently,

$$y'' = \frac{(y'^2 + 1)^2.(1 - y'^2)}{2\Big(xy'\,(3 - y'^2) - y\,.(1 - 3y'^2)\Big)} \quad - - - - - - \quad (B).$$

This is, then, the differential equation of the curve, in which the expression for the ardency is a maximum: it is of the second degree, and the integral cannot be obtained; but some of the qualities of this curve may, however, be deduced. It may at first be observed, that if $\int V\,dx$, for the curve in question, is to be a maximum between the two points A and B, (Fig. 22), we have for the two limits, $\frac{dV}{dy} = o$, or

$$x \,.\, (1 - y'^2) + 2\, y\, y' = o \quad - \quad - \quad \text{(C)}$$

when $x = a =$ DA, and when $x = o$; but when $x = a$, we obtain the ordinate for the point A, or $y = o$: hence, at this point, $a \,.\, (1 - y'^2) = o$, or $y'^2 = 1 \,.\, y' = \pm\, 1$; but $y' = \frac{d\,y}{d\,x}$ = the trigonometrical tangent of the angle DAF: that is, the angle DAF between the curve and the axis, is 45° at the point A.

From the above equation may also be seen, that $y' = o$ when $x = o$: i. e. the tangent BE of the curve at the point B is parallel to the axis.

The general expression for the radius of curvature r of a curve, is

$$r = \frac{\overline{1 + \left(\frac{d\,y}{d\,x}\right)^2}\Big|^{\frac{3}{2}}}{-\frac{d\,y^2}{d\,x^2}} = \frac{\overline{1 + y'^2}\big|^{\frac{3}{2}}}{-\,y''}$$

By substituting the values of y' and y'', before obtained, we have for the curve in question,

$$r = \frac{2 \,.\, x\, y' \,(3 - y'^2) - y\,(1 - 3\, y'^2)}{-\,(1 + y'^2)^{\frac{1}{2}} \,.\, (1 - y'^2)}$$

In this expression, r becomes infinite when $x = a$, y' being then $= 1$, as before found: i. e. the curve has an inflexion at the point A.

When $x = o$, r becomes $= 2\, y = 2\, c$, if DB = (C): that is, CB is the radius of curvature for the point B.

This may be enough to show the nature of the curve in which the expression of the ardency is a maximum, and to prove that this curve is not very sharp with respect to the axis.

It may now be proper to show, that the remarks inserted in Art. XLI. of 'Papers on Naval Architecture,' relative to the subject now in question, are without foundation.

Mr. Henwood begins by stating that "when a ship is sailing by the wind, as the particles of air impinge very obliquely on the surface of the sails, and as each particle, in gliding off after impact, takes off a part of the action of some of the more leewardly particles, the effective action of the wind on the sails

must be gradually diminished from the weather-side to the lee-side." He afterwards considers the action of the particles of water analogous to that of the air, and draws the conclusion "that whether a ship is full or sharp, forward or abaft, she would be more weatherly if made to sail on an even keel, than she would be if caused to swim by the stern, through an addition being made to the depth of the keel at the after end."— Although this conclusion is not legitimate, there would still be some reason for it, if the principle was true, or at least probable; but that this is not the case, will be easily seen by a proper consideration of the subject.

In fact, the particle of air or water *a* (Fig. 23), in gliding off after impact in the direction *b c*, receives the shock of another particle *a'*, proportional to the velocity and the weight of this particle, and is, by this shock, repelled in the direction *c g*. If the particles are perfectly elastic bodies, then the angle *a b d* is equal to *g b c*, and the velocity of the particle *a* after the shock in *b* is the same as before: consequently, two elastic particles, *a* and *a'*, of the same weight, will meet in the point *c* with equal velocities, and will obtain directions *c g* and *c h*, making equal angles with a line *f c* drawn parallel to the surface *d g*: hence the particle *a* will impel in *g*, under the same angle and with the same force it had in *b*. The other particle *a'* receives a shock in *h*, by a new particle *a''*, and takes the direction *h k*, parallel to *a b*, meets again the first particle *a* in *k*, and gives it the direction *k l*; so that it touches at *l* with the same force as in *g* or in *b*: this being repeated all the way along, the pressure or force on the surface must be equal all over. This is when the particles are considered quite elastic and independent of each other; but if they had been supposed to be but imperfectly elastic, and to have adhesion and friction, as is the case in elastic and non-elastic fluids, it would have been found that the angle *c b g* is less than *a b d*, and that the velocity of the particle *a* is less after the first shock in *b* than before, and consequently that it is repulsed towards the surface by the new particle *a'* with a greater force and under a greater angle than at *b*: it hence follows that the pressure is greater at the after end of the surface than at the foremost, or exactly the contrary to what Mr. Henwood has asserted.

is absolutely necessary they should have, in order to preserve a constant equilibrium between the resistance on the bottom and the force of the sails." It was before supposed, in the same remarks, that the ardency of Chapman's frigate was owing to her having heavy articles placed too near the bow. If both these conjectures are right, it is a proof that two exactly opposed causes give the same result.

Mr. Henwood appears not to have been aware that it is extremely easy to measure or estimate the effects produced by the differences of forms, when a measure of these differences and the corresponding effects can be given for a determined number of bodies. The question is simply this,—that for different forms represented by quantities $a, b, c \ldots m$, there exist different values $u, v, x \ldots z$, obtained from observation; and that, consequently, by the known methods used in all empirical investigation, a function u' of the variable quantity a' may be very soon found; such that when this variable quantity is equal to $a, b, c \ldots m$, the corresponding value u' is equal to $u, v, x \ldots z$; and, consequently, such, that when any other value between the limits a and m is given to a', a corresponding value of u' will be obtained, which approaches very nearly to what would have been found by experiment. It is presumed Mr. Henwood will admit, that, by these means, the effect of differently formed fore and after bodies upon the ardency can be estimated by the application of the parabolic method, when the observations proposed in Art. XXXIII. shall first have been made. In physical science little would have been known, if it had not been possible to deduce laws from a number of facts, as we seldom are able to find *a priori*, why things should be as we observe them, and not otherwise.

This question may be asked the author of the remarks:—If it is found, by observations and by calculations upon a great number of ships, that they invariably sail better when they approach very near to the parabolic method, or are constructed after it, is there not then a "shadow of a reason for supposing that a better vessel would be produced" by this method than without it, though we, in our limited sphere of knowledge, are not able to discover why it should be so? Chapman found this

to be the case, and his observation has not been denied by later experience: it may therefore be right to conclude, that, until the contrary shall have been shown, there is more reason to believe this than hypothetical conjectures; besides, it may be asked, are small dissimilarities the fundamental parts of the science of naval architecture? As Mr. Henwood says, if they are not, the advancement of the science cannot be impeded by the adoption of the above-mentioned method of construction.

ART. XII.—*A Method of laying Ships' Decks athwart-ships. By* MR. CHARLES WILLCOX, *of H. M. Dockyard at Portsmouth.*

IN the last Number of 'Papers on Naval Architecture,' the writer read with much attention a mode of forming ships' decks, by Mr. Henwood; the subject of which had been a consideration of the writer for some considerable time; it having occurred to him, at different periods, particularly while superintending the laying athwartships the after part of the lower deck and roundhouses of 10-gun brigs, that much advantage would be gained if the decks of ships generally were formed on this principle.

By the adoption of transverse decks, the extreme difficulty of obtaining beam-pieces would be diminished, and an advantage of greater depth in hold, and less height of the hull above water, would be afforded, with equal strength and durability, and a considerable reduction in the quantity of materials, and consequently in the expense.

Instead of laying plank on beams to form a deck, as at present, the writer proposes beams of reduced scantlings, placed at such a distance apart, that the space between them may be shut in by plank let down into rabbets in the sides of the beams; so that the beams, and plank between them, together, may form an athwartship deck.

The decks of an 84-gun ship will be now described. The beams of the orlop deck, on the present plan, are $14\frac{1}{2}$ inches square; the beams, in the proposed plan, are to be 10 inches

moulded, and 13 inches sided; each piece to be in length, from the timbers, to 1 foot 8 inches beyond the side of the hatchways on the opposite side; every beam-piece (*a a*, Fig. 25,) being coaked and bolted to the adjoining piece. From these beam-pieces a rabbet is to be taken out, an inch wide and 4 inches deep (Figs. 25 and 27), which will extend from the inner part of the waterway to 2 inches on the end of the adjoining beam-piece, which forms a stop at the butt for the caulking; a deck plank, of 4 inches thick and 15 inches broad, is intended to be placed between the beams, resting on the rabbet (*b b*, Fig. 25 and 27); the deck plank to be secured, on the under side, by small dog-bolts driven into the beams, at the lower part of the rabbet, at about every four feet distance from each other; in the plate of the dog-bolt is to be a hole, which a screw will be turned through into the deck-plank, for its fastening. This method will form a substantial support for the deck-plank, and render the liability of leaking much less. By this mode, a good stop for the caulking would always be insured, and the frequent necessity of shifting decks, in consequence of large seams, and decay, by the effect of iron fastening driven from the upper side, obviated. In the cable tiers, gratings may substitute the deck-plank proposed; by which a good circulation of air would be produced.

Under the beams, at each side of the hatchways, are proposed to be placed two binding-strakes, 4 inches thick (*c c*, Fig. 25 and 28), and being, together, 20 inches broad, worked top and butt, or anchor-stock fashion, bolted together, and secured to the beams and hooks, with coaks and screws, will support and tie the beams together in a fore and aft direction. Under these binding-strakes are to be placed pillars, which will stand on a keelson, extending fore and aft the ship; on each side of the midship one (giving an additional security to the floors and first futtocks), the dimensions of which may be reduced, in consequence of having two in addition to our present practice. Pillars, thus placed, have been already adopted in the Columbine, and have been found to answer well, both for support and the convenience of stowing tanks, &c.

The other decks to be formed on the same principle. The beams, deck-plank, and binding-strakes, to be of the following

dimensions:—The gun-deck beams, 11 inches moulded and 13 inches sided; deck-plank, 4 inches thick and 15 inches broad; binding-strakes, 4 inches thick and 20 inches broad.

The upper-deck beams, 10 inches moulded, and 13 inches sided; deck-plank, 4 inches thick and 15 inches broad; binding-strakes, 4 inches thick and 20 broad.

Quarter-deck and forecastle beams, 9 inches moulded and 13 inches sided; deck-plank and binding-strakes, the same as the latter.

Roundhouse beams, 7 inches moulded and 13 inches sided; deck-plank, 3 inches thick and 15 inches broad; binding-strakes may be omitted.

The waterways, on the present plan, for the gun-deck, are from 13 to 14 inches square; those proposed are to be 13 inches moulded and 11 inches sided, (waterways for other decks to be in the same proportion,) the form of which to be precisely on the same plan as the present thick waterways (*d d*, Figs. 26 and 27,) except in not scoring over the beams, having a rabbet taken out, in the usual way, the depth of the deck-plank; the waterway to be let down into the beams and coaked, as is now the practice, of such a depth that the upper part of the rabbet of the waterway shall bear on the upper side of the beam, which will be beaten back to correspond with the rabbet forming the waterway seam.

The shelf-pieces to be of the same dimensions as the present, coaked to the beams, and bolted, as is now the custom.

One chock under the shelf, between every two ports, may be considered necessary, to resist the pressure of the beams, deck, and weights thereon. To the front of these chocks are to be fitted iron knees, (*e e*, Figs. 26 and 27,) as an additional tie to the beams and the ship's sides; a part of the crown of the knee forming a tenon, to be let up into the beam; the arm of the knee under the beam to be one foot in length, the end of which to be of a T form, extending to the sides of the beam; in this arm are to be two screws, an inch in diameter and 8 inches long, for the gun-deck, and for other decks in the same proportion, with a square head, to be turned up into the beam by means of a spanner: these screws will be equally as secure as bolts, with the advantage of not going through the deck. One

collar-headed bolt is to be driven between the two screws, nearer the throat; the point of the bolt will be a screw, an eighth of an inch less in diameter than the other part, which will prevent the thread of it from being clogged by driving. The top of the bolt-hole, previous to driving the bolt, is to be bored down with a ring-engine, three inches deep; into this hole a circular washer and nut will be put over the screw of the bolt, and turned on tight; a plug is then to be driven on it and caulked, to prevent the probability of a leak by the bolt. That part of the knee on the front of the chock and shelf, is to be bolted in the usual manner, except having a screw in the toe of it, similar to those in the T arm. When this knee is put into its place, the screws are to be turned in first, which will keep the knee fixed while boring through the bolt-holes and driving the bolts.

At the hatch, and ladder ways, carlings (*f*, Fig. 28,) will be let down between the beams, with a double stop, which will form part of the comings, standing above the deck 4 inches; the comings are to be coaked or rabbeted to the top of these carlings. The head-ledges are to be let down into the beams two inches and a half, for caulking, and coaked to the beams, halving over the comings, and bolted in the usual way; a rabbet is to be taken out of the side of the carlings, to receive the ends of the deck-plank; half-beams (*g*, Fig. 28,) will also be let down into the carlings, and be secured to them with dog-bolts: and that part of the half-beams above the rabbet, which is taken out of them to receive the deck-plank, will rest on the rabbet of the carling, forming a double stop; by which there will be the same depth of caulking against the comings as in any other part of the deck.

The mast-partners to be fitted in a similar manner.

As two rows of pillars are intended to each deck, under the binding-strakes, it is proposed that they shall be made of iron, which will be neater, and occupy less space. Iron pillars, on the present plan, rarely answer the intended purpose, as they oftener bear on the bolt which forms the hinge, than on the head of the pillar. The writer would propose them to be made in the following manner: a circular cast-iron cap, about 8 inches in diameter, with a spherical cavity in the under side of

it, suitable to the round head of the pillar; the cap is to be formed with ears, between which the head of the iron pillar is to be fitted, forming the hinge. The hole in the pillar, for the bolt hinge, instead of being round is to be an inch longer than the diameter of the bolt, which will admit of the pillar bearing only on its head, in the corresponding socket, and to step into a base similar to the cap; each of which to be secured in their places by screws, which will render them more easy to be shifted.[1]

In speaking of the advantages gained by adopting this plan of fitting decks athwartship, it may be observed, that the beams, half-beams, carlings, ledges, binding-strakes, and flat of deck, on the present plan, amount to about 6900 cubic feet; whereas, the one proposed would be 5800 cubic feet: consequently, 1100 cubic feet of timber would be saved, and the expense of workmanship very considerably lessened. The depth in hold would be increased 16 inches, and the height of the ship's hull decreased 10 inches, which is gained by adding to the present height the thickness of the decks, and the difference between the moulding of the present beams and those proposed; supposing the gun-deck ports to remain above the load draught of water the same distance as at present.

The beams, being placed in the uniform manner proposed, would give more than double the number to each deck, compared with our present plan; consequently, much more security is gained, by the attachment of the beams to the side, although more than half the present number of iron knees are dispensed with; which, with the removal of the weight from the decks, will amount to upwards of 100 tons.

The beams being placed at the side 13 inches apart, and the deck-plank coming between them, resting on the rabbet taken out of the beams, will more nearly equalize the strength of the deck throughout, than the present plan, and will give a substantial resistance to the recoil of the guns, when fired, as well as to their momentum, when the ship is labouring in a heavy sea.

This mode of constructing decks will cause no alteration in

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[1] A jack-in-the-box should be used in all cases of turning up pillars, or taking them away; it being too often the case, that much damage is done by striking them violently with a maul, to get them out of their place.

the fitting of the hammock-rack, &c., which is attached to the side of the beams; also, a free circulation of air will be admitted, between the ends of the beams, into the openings between the timbers.

The present plan will possess the advantages which have so frequently been considered desirable, of fitting decks without the fastenings going through from the upper side, in order to prevent leaks, and to afford a reconversion of the timber when it may be seen necessary to shift it.

To connect the different parts of a ship together, so that, when any part may require to be shifted, it may be done without incurring much trouble or expense, is one of the most important considerations in practical ship-building. The proposed plan affords, in this respect, every facility.

Art. XIII.—*A Plan proposed for extinguishing Fires on board Ships.*

(*To the Editors of Papers on Naval Architecture.*)

Gentlemen,—I beg to submit for insertion, in the Papers on Naval Architecture, the following description of a method of extinguishing fires in ships. I am aware that difficulties may arise in the practical execution of my proposal; yet I cannot doubt but that they may be surmounted by attention and perseverance: whilst the confidence I may justly entertain in the well-known principle I have assumed, emboldens me to hope the plan may be ultimately rendered not unworthy of consideration.

I am, Gentlemen,

Your obedient Servant,

George Courtney.

School of Naval Architecture,
H. M. Dock-yard, Portsmouth,
16th May, 1828.

The instrument proposed, for the purpose of admitting water into a ship, is formed on the principle of the syphon. A bent

copper tube, one foot in diameter, is placed through a port, having one arm outside the ship, extending to a small depth below the water's surface; the other inside, passing through the gun-deck and orlop, to the lower part of the hold. Let the instrument, thus placed, be supposed filled with water, and the two orifices closed; if they be then unclosed, the water will flow out at the orifice inside the ship, which is at a considerable depth below the water's surface, whilst the pressure of the atmosphere, forcing the fluid through the tube from the outside, will cause a constant stream to be maintained as long as may be required. Two valves are fitted closely over the orifices, which may be opened or shut by rods fixed to them, and brought up to the part of the instrument which rests on the portsill. These valves are for the purpose of more conveniently filling the instrument; and, by their means, its action may be made to commence or cease at any instant. It will be further necessary to immerse the orifice in the hold, a few inches, in a vessel of water, to prevent the admission of any particles of air, which may otherwise penetrate into the tube, at this place, in so considerable a degree, as eventually to stop its action.

It is suggested that an instrument of this kind be supplied to all ships. If, in ordinary, it be fixed in the above position, and filled with water (the valve inside the ship being shut, and that outside open, and secured back), this precaution will cause whatever leakage takes place at the inner valve to be supplied, and, at the same time, furnish a constant test to ascertain the state of the instrument. On discovering a fire to have commenced, the person on board has only to open the valve in the hold, by means of the rod brought up to the portsill, when the instrument will instantly be in full action. The adjoining ships, in the mean time, should send their syphons in their boats, and dispose them as quickly as possible through any port the fire will permit; for which purpose, every facility may be afforded in the disposition of the spaces left in the decks for the circulation of air. Thus the ship may be rapidly sunk to her portsills; the syphons then stopped, by closing the outer valves: and thus all the difficulty and expense of raising the bottom will be avoided.

Whilst the ship is being sunk, it will be necessary to plug up

those holes with which some of the planks in the buttocks are usually perforated, for the admission of air; at the same time, the gun-deck scuppers must be also plugged, and the gun-room ports and air scuttles in frigates caulked.

It is presumed, the above instrument may be admitted to combine the following advantages:—

1. Simplicity; including the trifling expense of its construction, and the great improbability of its getting out of order.

2. The facility with which it is put in operation, and the continuance of its action without manual labour.

3. The power possessed of stopping its action at any instant; by which means, the expense of raising a ship in harbour is saved, and a security afforded against the effects of accident.

It is further proposed, that a few alterations (to be hereafter particularized) be made in the orlops of ships of the line, and lower decks of other ships, so as to render these decks capable of being entirely covered with water. Another syphon, with its inner orifice just above these decks, must be also supplied, for the purpose of admitting the water, in the event of fire. With these arrangements, on an alarm of fire, the orlop or lower deck may be immediately converted into a reservoir of water, which it is conceived will interpose a complete barrier to prevent the communication of the flames from the hold to the upper works, or from the upper works to the hold. On this supposition, if the fire should have commenced in the hold, by thus preventing it from extending upwards, whilst the hold is being rapidly filled with water, it will be shortly extinguished, with the loss of the works in the hold alone. The importance of this is considerable, even in ships in ordinary; but how greatly is it increased in ships at sea, if it is considered that those fires, which are usually most fatal, might be thus, with great probability, extinguished, and the loss of many valuable lives prevented.

Supposing the fire to have commenced on the decks of a ship in ordinary, she may be sunk till the gun-deck is below the water's surface, and covered with water; when the syphons should be stopped, taking care to plug up the scuppers. Thus the whole of the ship below the gun-deck sills may be preserved, whilst the usual means are resorted to for saving the top-sides.

In a ship at sea, under the above circumstances, the crew

should take to the boats and spars, and, whilst the ship is being sunk by the syphons, exert every possible means to preserve the gun-deck till it is sunk below the water's surface, and covered as described above. This deck, when the fire shall have burnt out, will answer the purpose of a raft; and if the pumps are uninjured (for which purpose every thing connected with them should be of metal), the crew may be able to get to the provisions, and in favourable weather may, perhaps, in many instances, be saved.

The alterations necessary, in the orlops and lower decks of frigates, must be now considered. In frigates and small vessels, nothing further will be necessary, than to have the comings round the hatchways and mast-partners of sufficient height. On the orlop decks of ships of the line, besides the height of the comings, a cant must be fixed at the after part, to prevent the water from flowing into the bread room; the wing gratings substituted by solid scuttles, and perhaps the plank under the cable tier may be half an inch thicker, to allow of its being caulked. Ships in ordinary will also require cants to be fixed round those spaces left in the decks for the admission of air. It is presumed, the expense and inconvenience produced by these alterations would be inconsiderable.

It would be very advantageous to have, at least, two athwart-ship bulkheads caulked with penstocks in the limbers, capable of being screwed down from the gun-deck; by which, a fire below would be extinguished much more rapidly, and with much less injury to the provisions and stores.

The hold of a three-decked ship in ordinary, it is considered, may be filled by sinking her not more than 5 feet 10 inches. This space will diminish with the class of ship: in a 10-gun brig, not more than 2 feet 3 inches will be requisite. It is manifest how considerably it will be diminished when the stores and provisions are stowed. A 74-gun ship, in ordinary, will require about 1300 tons of sea-water to fill her hold; and, supposing her fitted with a syphon of each kind above described, this may be accomplished in less than two hours.

Art. XIV.—*Remarks on the Resistances of Fluids. By* John Wilson, Esq., *of the Navy Office.*—Continued from Vol. I., Art. XLVI.

In the application of the theory of the resistance of fluids, as detailed in Vol. I., Art. XLVI., to solid bodies moving in *water*, we cannot, by a process similar to that we used for air, find what part of the total resistance should be taken for the impulsive, and what part for the removing resistance; there being no recorded experiments of the total resistance of planes of various sizes, moving in water, which there are of such planes moving in air. But, as there are many accounts of solid bodies moving in water, with prows forming various angles of incidence to the direction of their motion, we will endeavour, from them, to ascertain the proportion of the two resistances. In the first place, it will be necessary to point out the difference which exists between the resistance of air and of water, as applicable to objects of naval science.

When a plane passes through the air, the resistance it experiences is, with the velocities incidental to the above limitation, altogether, or nearly so, on the anterior surface; for such is the expansibility of air, that it will continue to press on the posterior surface, with nearly a constant force: therefore, the minus pressure, in this element, is so small, that it may be neglected without producing any sensible error. But, when a vessel is moving in water, even with a small velocity, it causes a depression of that element at the after part of the vessel, which indicates, and indeed arises from, the partial vacuity at that part, and, consequently, a less pressure than when the vessel is at rest: hence the necessity of taking the minus pressure into account, particularly in such small bodies as are used in experiments.

It appears, from the Report published by the Society for the improvement of Naval Architecture, that some thousands of experiments were made under their direction, on bodies of various shapes moving in water; the results of which were communicated in that publication. The horizontal sections of those which are applicable to our purpose, are represented in Fig. 29,

where A, *a*, *a*, &c., are the foremost extremities, B is the after extremity, and C the midship body: this latter part was, in length, breadth, and depth, one foot. The resistances at a velocity of one knot an hour, after deducting the friction, were as follows:—

Angle of the foremost Extremity.		Angle of the aftermost Extremity.		Resistance in lbs. avoirdupois.
°	′	°	′	lbs.
180	0	19	10	2,31
60	0	19	10	,77
38	56	19	10	,62
28	56	19	10	,52
19	10	19	10	,44

When the motion of these bodies was reversed, making the end B the foremost extremity, and the ends A, *a*, *a*, and *b*, the after extremities, the resistances were,

Angle of the foremost Extremity.		Angle of the aftermost Extremity.		Resistance in lbs. avoirdupois.
°	′	°	′	lbs.
19	10	180	0	,89
19	10	60	0	,93
19	10	38	56	,63
19	10	28	56	,59
19	10	19	10	,44
19	10	12	50	,40

To ascertain, from these tables, the minus pressure, it will be necessary to represent the resistances by a curved line of such a nature, that the length of the fore bodies in one case, and of the after bodies in the other, be the abscissas, and the respective resistances be the ordinates of that curve. This is shown, in Fig. 29, by the lines *d*, *d*, which represent the resistances given in the first table, and *e*, *e*, those given in the second table. The conductors of the experiments, observing the very little diminution of the resistance, obtained by lengthening the after body from 3 feet to 4 feet 6 inches, concluded that, in

such a body, there was no minus pressure. But, if the curves of the resistances *d, d, e, e,* be examined, as far as they can be compared together, and also the curves *f* and *g* (Fig. 30), it will be perceived that, by lengthening the fore body, a still less diminution of the resistance takes place: therefore, the conclusion the Society came to, must be considered as without proper foundation. The probability is, from the comparison of the curves, that when the extremity of the after body was 19°10′, the minus pressure was something greater than the plus pressure, and that, if it be taken at ,2, it will be very nearly the true quantity; which, subtracted from the resistances before given, will leave the plus pressure only. Now, if we take the impulsive resistance in proportion to the squares of the sines of the angles of incidence, and the removing resistances as a constant quantity, we shall have,

Angles of Incidence.		Plus Pressure, by Experiment.	Resistances.		
			Impulsive.	Removing.	Total.
°	′	lbs.	lbs.	lbs.	lbs.
90	0	2,11	1,97	,14	2,11
30	0	,57	,49	,14	,63
19	28	,42	,22	,14	,36
14	28	,32	,12	,14	,26
9	35	,24	,06	,14	,20

As the forms of ships never even approximate to those of the bodies from which the foregoing resistances are taken (the longitudinal sections of the former being bounded by fair curves, and those of the latter by straight lines and angles,) it will be necessary more particularly to consider the resistances to bodies whose sections, in the direction of their motion, are formed by curved lines. These resistances we will take from the same valuable Report the others were taken from. Fig. 30 represents the horizontal sections; A, *a, a,* the foremost extremities; B, the aftermost extremity; and C, the midship body; *f* and *g*, the curves formed, as in the case of the angular bodies, representing the plus and minus pressure: *f* being that formed when

A, a, a, are the foremost extremities; and g that when the motion of the bodies is reversed.

Form of the fore Body.	Angle of the aftermost Extremity.		Resistance.	Resistance when the Motion is reversed.
	°	′	lbs.	lbs.
Semicircular....	19	10	,57	,71
Segments of circles, radius being equal to breadth..	19	10	,46	,94
Parabolic, nearly	19	10	,36	,40

From the results in the last column, it will be perceived how enormously the resistance is increased by a greater fulness in the after body of a vessel.

If, from the sum in the third column of the last table, we subtract the minus pressure before determined on, and take the impulsive resistance for the fore bodies, calculated by the common formula, which will be in the ratio of the numbers ,666, ,417, and ,059, we shall have,

Form of the fore body.	Plus Pressure, determined by Experiment.	Resistances.		
		Impulsive.	Removing.	Total.
	lbs.	lbs.	lbs.	lbs.
Semicircular....	,37	,23	,14	,37
Segments of circles, breadth equal to radius	,26	,14	,14	,28
Parabolic, nearly	,16	,02	,14	,16

These resistances come out as near to those given by the experiments, as can reasonably be expected.

We will now apply these results to the experiments of Romme, who found but little difference in the resistances

between an exact model of a ship of 74 guns, made on a scale of one inch to a foot, and another model having precisely the same midship section and length; but, instead of the longitudinal sections being bounded by fair curves, they were made by straight lines and angles, similar, but in different proportions, to those represented in Fig. 29. A 74-gun ship's midship section is 800 square feet, and her length 180 feet: these quantities, reduced in proportion to the models, will be 5,55 square feet for the areas of their greatest transverse sections, and 15 feet for their lengths. The form of the longitudinal sections of a 74-gun ship, the model of which is the one we will begin with, is nearly that of the parabola given in the last table, but a little fuller. We will, therefore, take the impulsive resistance at ,04: this, multiplied by 5,55, the area of the midship section, gives ,222 for the resistance due to the impulse: the cube of the square root of 5,55, equal to 13,2 multiplied by ,14, gives 1,848 for the removing resistance; making a total, for the head pressure, of 2,07. To find the minus pressure, we must compare the resistance shown in the last table but one, when the after body was of parabolic form, to that in the first table, where the after body was wedge-shaped, and of an angle, at the extremity, of 19°10′. Now, as the fore bodies of both are the same, the difference, ,04 lbs., subtracted from ,20, the minus pressure of the after body, with its extremity of 19°10′, leaves ,16 for the minus pressure of the after body of the parabolic form; which is nearly that of the diagonal longitudinal sections of a 74-gun ship, in the after body: this quantity, multiplied by the area of the midship section, produces ,888 for the minus pressure, which, added to 2,07, the plus pressure, gives the sum of 2,958 for the total resistance. The friction may be neglected, as it is the same in both models. We will now compute what resistance the other model ought to sustain. The half length of the ship is 90 feet; the mean of the half breadth and depth of the ship is 22,5 feet nearly: therefore, the square of the sine of the angle of incidence is to the square of radius, as ,0625 to 1; giving the relative proportion for the impulsive resistance, between the fore body of this model and that of the fore body of a parabolic form, as ,0625 to ,059: this will give us, for the impulsive resistance, ,019 multiplied by 5,55, equal

to ,105; which, added to the removing resistance, 1,848, before found for the model of the 74-gun ship, gives a total, for the head pressure, equal to 1,953. The after body of this model being wedge-shaped, and of a mean angle, at the stern, of 16°, we will take the minus pressure at ,18; which, multiplied by 5,55, produces ,999 for the minus pressure; and this, added to 1,953, gives 2,952 for the total resistance, coinciding with the computed total resistance for the model of the seventy-four, as nearly as was ever obtained from two experiments, even on the same model. From this investigation, it appears that, by taking into consideration the removing resistance, those experiments of Romme, which have hitherto been thought anomalies in naval architecture, are fairly accounted for.

The next application we shall make of these tables will be, to ascertain the resistance which a frigate of 46 guns will meet with in her progress through the water, and compare it with the power of the wind on her sails. To do this with a due regard to correctness, it will be necessary, in order to find the impulsive resistance, so to divide the fore body by transverse and horizontal sections, placed at such equal distances apart, that the part of the surface of the body between one section and the next may be considered as a plane. This will be nearly accomplished by making the transverse sections 4,9 feet apart, and the horizontal ones 3,2 feet apart. The usual method is, to divide the trapeziums, formed by the horizontal lines and transverse sections on the fore body of the ship, as represented on the draught, into two triangles; but as we can arrive at the same degree of accuracy, and with little more than half the trouble, by measuring the trapeziums instead of the triangles, we will, therefore, adopt that mode of proceeding; the results of which are contained in the following table :—

Trapeziums between the 1st and 2d horizontal Lines.

Between what Sections.	Mean Breadth of the Trapezium.	Distance between the Sections.	Square of the Sine of the Angle of Incidence, divided by the Square of the Radius.	Product of the 2d and 4th Columns.
Stem and 1	5,5	3,3	,310	3,05
1 2	4,4			
2 3	3,0	2,3	,180	,54
3 4	2,1	1,6	,098	,21
4 5	1,5	1,2	,041	,06
5 6	1,1	,8	,026	,03
6 7	,7	,5	,013	,01
7 8	,5	,4	,006	,00
8 ⊕	1,2	—	—	,00
Total....	20,0			3,90

Trapeziums between the 2d and 3d horizontal Lines.

Between what Sections.	Mean Breadth of the Trapezium.	Distance between the Sections.	Square of the Sine of the Angle of Incidence, divided by the Square of the Radius.	Product of the 2d and 4th Columns.
Stem and 1	2,5	2,5	,220	1,54
1 2	3,5			
2 3	3,2	1,9	,130	,42
3 4	2,4	1,4	,076	,18
4 5	1,9	1,2	,056	,11
5 6	1,4	,9	,033	,05
6 7	,9	,6	,015	,01
7 8	,6	,5	,010	,01
8 9	,5	,4	,006	,00
9 ⊕	1,0	—	—	,00
	17,9			2,32

Trapeziums between the 3d and 4th horizontal Lines.

Between what Sections.	Mean Breadth of the Trapezium.	Distance between the Sections.	Square of the Sine of the Angle of Incidence, divided by the Square of the Radius.	Product of the 2d and 4th Columns.
Stem and 1	,6	1,9	,130	,35
1 2	2,1			
2 3	2,4	1,8	,119	,28
3 4	2,3	1,4	,075	,17
4 5	2,0	1,2	,057	,11
5 6	1,8	1,0	,033	,06
6 7	1,5	,9	,020	,03
7 8	1,1	,7	,015	,02
8 9	,8	,6	,010	,01
9 10	,6	,5	,004	,00
10 ⊕	1,0	—	—	,00
	16,2			1,03

Trapeziums between the 4th and 5th horizontal Lines.

Between what Sections.	Mean Breadth of the Trapezium.	Distance between the Sections.	Square of the Sine of the Angle of Incidence, divided by the Square of the Radius.	Product of the 2d and 4th Columns.
Stem and 2	1,0	1,0	,040	,08
2 3	1,0			
3 4	1,3	1,0	,040	,05
4 5	1,4	,9	,033	,05
5 6	1,5	,8	,026	,04
6 7	1,4	,7	,020	,03
7 8	1,4	,7	,020	,03
8 9	1,3	,5	,010	,01
9 10	1,0	,4	,006	,01
10 ⊕	1,8	—	—	—
	13,0			,30

Trapeziums between the 5th horizontal Line and Keel.

Stem and 3	,7			
3 4	,4	,5	,010	,010
4 5	,4	,5	,010	,004
5 6	,5	,5	,010	,005
6 7	,6	,5	,010	,006
7 8	,7	,4	,006	,005
8 9	,9	,4	,006	,005
9 10	,9	,4	,006	,004
10 11	,9	,4	,006	,004
11 ⊕	2,2	—	—	,000
Total of the mean breadths of the trapeziums........	8,2			,048
	75,3		Total of the products....	7,60

If the sum of the products in the last column, which are the proportions of the impulses, be divided by the sum of the mean breadths of the trapeziums, we shall have ,101 for the ratio of the impulsive resistance. By referring to the last table but one, we shall find that, when the ratio is ,666, the impulse is ,23 : therefore, at ,101, it will be ,035 ; this number, multiplied by 505, the area of the midship section, produces 17,67 for the impulsive resistance; 505, raised by the $\frac{3}{2}$ power, is 11362, which, multiplied by ,14, will give the removing resistance 1590. The minus pressure is 505 × ,2 = 101,: therefore, the total resistance, at the velocity of one knot an hour, exclusive of friction, is 1709, the sum of the three resistances. This frigate, in sailing large, with a strong breeze, attains the velocity of 10,4 knots an hour; and as the resistance is as the square of the velocity, at this rate of sailing, her plus and minus pressure amounts to 184572. The friction on a square foot of surface, at the mean draught of water of this ship, and moving at the above velocity, was found, by the Society for the improvement of Naval Architecture, to be 1,02; this, multiplied by 8100, the area of the surface of this ship's bottom, equal to 8262; and this sum, added to the plus and minus pressure, will give 192824 for the total resistance, at the velocity of 10,4 knots an hour.

We will now see what the force of the wind amounts to, on the sails actually set in this ship, sailing free, when she had attained the velocity before mentioned. The calculation will be performed by the rules given in Vol. I., Art. XLVI. The sails, being braced to an angle of 82° to the direction of the wind, and of 26° to the athwartship line of the ship.

Names of the Sails.	Areas of the Sails, in square feet.	Efforts of the Sails.		
		Impulsive Resistance.	Removing Resistance.	Total Resistance.
Fore-course	3353	2000	49500	51500
Fore-topsail..........	2876	1710	39100	40810
Fore-top-gallant-sail ..	985	580	7660	8240
Fore-royal	373	220	1820	2040
Main-course	3093	1840	43400	45240
Main-topsail	2354	1390	29000	30390
Main-top-gallant-sail ..	1274	750	11440	12190
Main-royal	477	280	2660	2940
Driver	1715	1020	18000	19020
Mizen-top-sail	923	550	7120	7670
Mizen-top-gallant-sail	486	290	2730	3020
				223060

This sum, reduced in the proportion of radius to the sine of the angle which the yards make with the longitudinal axis of the ship, will be 200480; which is very nearly the same as computed for the total resistance of the ship.

Notwithstanding the results of the calculations have proved so satisfactory, it is probable that the numbers which have been assumed for the impulsive and removing resistances are somewhat inaccurate. Indeed, perfect accuracy in the computations of the resistances of fluids can only be expected when experiments are conducted, not only by able and scientific men, but on a magnitude such that a government only can command. And what government so proper to issue such commands, as the one which presides over the energies and resources of the greatest maritime nation in the world?

Art. XV.—*Notice of 'The Complete Mathematical and General Navigation Tables,' by Thomas Kerigan, R.N.*

Of the numberless advantages which the useful arts have derived from science, perhaps the greatest is the power of directing, on the trackless ocean, the mighty fabrics borne on its bosom, with certainty to their destination. It is a proud and highly gratifying consideration to the astronomer, that the discoveries made in his retirement are of the greatest practical advantage, in some of the most important circumstances of active life; that, while resting in the security of the land, he has reduced the dangers of navigating the seas.

Pleasing as it is to admire the abstract beauty of the discoveries of the philosopher, and to follow his investigations through all their intricacy and research, the value of his labours is more fully estimated, when their results are rendered applicable to professional pursuits. For general use, it is necessary that the scientific results of discoveries be embodied in easy practical rules, which may be readily applied, by arithmetical calculations, to the determination of any particular object required. To facilitate the arithmetical operations, and to reduce the probability of errors in them, it has been found highly advantageous to form tables of the results of such calculations, as are commonly involved in the application of these rules to the solution of particular questions.

In nautical astronomy and navigation, tables of results are absolutely necessary, to render the observations of the mariner capable of immediate practical use. This science admits of, and requires, more numerous tables for general use, than any other: indeed, many of the simplest and most useful operations in navigation are rendered practicable at sea, only by means of such references. The numerous works containing general navigation tables have gradually been much improved and enlarged, till they are, at length, arrived at great general efficiency; the subject, however, is so dependent on future discoveries, that we are unable to limit the improvement it is capable of: it is of such practical importance, that every new or improved table and rule, which in any way gives facility to the mariner, merits our attention and gratitude.

The work of Mr. Kerigan comprises two volumes: the first giving the description and use of the tables which form the second volume, with their application to navigation and nautical astronomy. Many of the tables are arranged in a more convenient manner than has been hitherto done, and some of the tables are new, and they are generally adapted to the best methods of calculation. In some of these tables, the results are carried to the utmost limits of every possible case; preventing, thereby, the necessity of a calculation for correction, which tables of a less extent may occasionally require.

In Tables XIII. and XIV., the equations to equal altitudes of the sun are adapted to proportional logarithms, by which they are much simplified. The author expresses a hope, that,

by their means, "the truly correct and excellent method of finding the error of a watch or chronometer, by equal altitudes of the sun, will be brought into more general use." The correction of the auxiliary angle, in the observation of the moon's distance from a planet, is given in Table XXI., which is very useful in finding the longitude by the moon's central distance from a planet. As it is intended to give, in the Nautical Almanacs, the moon's distance from the planets, the correction of the logarithmic difference when the moon's distance from a planet is observed, which is inserted in Table XXVI., will be very useful in computing the lunar observations. The general traverse table, Table XLII., is very well arranged: it obviates the inconvenience, frequently felt, of having to refer to two tables in finding the difference of latitude and departure corresponding to any given course and distance. Table XLIV. contains the mean right ascensions and declinations of 236 of the principal fixed stars, adapted to the beginning of the year 1824, arranged according to the order of right ascension in which they arrive at the meridian. The eighth column of this table contains the bearing, and the true spherical distance, of an adjacent brilliant star; which facilitates the method of deducing the latitude from the altitudes of two fixed stars. The last column of the table contains the annual variation of the true spherical distance; by which the tabular distance may be easily altered for a future period. Tables L. and LI. are computed to enable the meridional altitude of the sun, or any other celestial object, whose declination does not exceed 28 degrees, to be obtained, within certain intervals from noon for the sun, and from the time of transit over the meridian for any other celestial object, when the observation cannot be taken at the time of the object's coming to the meridian, which frequently happens at sea, by the intervention of clouds. They are adapted to proportional logarithms, which renders the operation of determining the latitude very simple; while it is more correct than by the troublesome method of double altitudes.

The principles of many parts of the science are well illustrated. The illustration of the augmentation of the moon's semi-diameter is very perspicuous: its variation as the sine of the angle contained by straight lines drawn from the moon at any altitude to the extremities of the distance representing the aug-

mentation of the moon's semidiameter when in the zenith, to the radius equal to the distance from the moon to the centre of the earth, is correctly given, although not proved. Indeed, the author professes rather to give illustrations of the principles, than strict proofs of problems by mathematical investigations. We consider, however, that the author might very advantageously have substituted scientific investigation for several subjects contained in his work: such as, gunnery, gauging, and particularly the problems in the Appendix, on compound interest and the present worth of freehold estates; which, however useful, cannot properly be considered as belonging to a work on navigation and nautical astronomy. An ingenious problem is given at page 371, communicated to the author of the tables by Captain W. F. Owen, for finding the true latitude of the place of observation, having given the latitude by account, the true altitude of the sun's centre, and the apparent time. The peculiarity of this method is, that the observation may be taken at any hour before or after the sun's transit, as it does not require that the interval from noon should be governed by the object's meridional zenith distance. This method, however, requires the apparent time to be very correctly known, particularly where the sun comes very near the zenith of the place of observation.

Mr. Kerigan explains, very clearly, the method of sailing on the arc of a great circle. Its advantage in long voyages, where no causes prevent its adoption, such as particular winds, or the interruption of land, is very considerable. The shortest distance between any two points on a sphere, is evidently the arc of a great circle passing through the two points. The course in the loxodromic curve, or rhumb line, can therefore never be the shortest distance between two places, except they lie in the same meridian, or in the equator. The property of the rhumb line is, that it always makes the same angle with the meridian; so that the course remains the same, when a ship sails by this method. The course on an arc of a great circle, except under a meridian or under the equator, is continually changing; but, as this is inconsistent with the practice of sailing, as many points are fixed on, in the arc of the circle, as may be thought necessary for correctness, and their longitude and latitude determined, with the respective courses and distances between

them. The author gives two examples at length: the one from the Cape of Good Hope to New South Wales; and the other from Port Jackson to Valparaiso. The latter was the route of His Majesty's ship Dauntless, commanded by Captain G. C. Gambier: the alteration in the course having been made at every five degrees of longitude. "The sum of the several distances, measured on the respective rhumb-lines intercepted between the successive longitudes and latitudes, is 6108,73 miles; but the true spherical distance, on the arc of a great circle, is 6107,87 miles; the difference, therefore, is only 0,86, or a little more than three-fourths of a mile: which is a very close approximation in the measure of so great an arc. The distance, by Mercator's sailing, is 6853,16 miles; which is 745,29, or about 745¼ miles, more than by great circle sailing." We shall have occasion, at a future time, again to refer to this work, and to speak of the correctness of the rules.

The work of Mr. Kerigan is a valuable practical work, well adapted to the present general state of knowledge of professional men; but, at the same time, it is to be regretted that the knowledge generally possessed by professional men is not of that scientific character, as to render works on navigation necessarily of a higher order. Instead of rules being given by an author, the truth of which rests on his assumption, assisted by his illustrations; we consider it most desirable, that those who use the rules may know their truth, by a full acquaintance with the principles on which they are founded, and by an examination of their proof. Such a degree of knowledge, involving a considerable acquaintance with astronomy and mathematics, we consider perfectly within the limits which most professional men may attain, consistent with the execution of all other professional duties. It may be objected, that the duties of a naval life require a very early admission to its practice; that boys must necessarily relinquish, at a very early age, the advantages derived from education on shore; and that, even in those cases where the greatest attention has been paid to their professional education, they are frequently found, at a more advanced age, to retain but little of that knowledge, which must have been too hastily obtained to possess generally any great permanent advantage. A course of studies on shore, following the present professional education on board ship, at

an age better prepared to appreciate its value, would tend more to raise the scientific knowledge of naval officers, than any course of studies, at an early period of life, could possibly effect. In most professions, the authors of discoveries and improvements in their theory, as well as practice, are found generally in the ranks of their respective followers: we can see no sufficient reason why this should not be the case in naval, as well as in other sciences.

Art. XVI.—*Observations on the Forces which act on a Ship when in Motion, as they affect her Ardency; with a view to determining the correct Position of the Masts.*

The labours of the numerous men of science, who have devoted a portion of their attention to the different problems embraced in the "Theory of Ships," have left but few of its abstract principles uninvestigated. Most of the properties of ships have been examined, and the laws on which they depend clearly defined, either by the aid of mathematical demonstration, or by induction from experiments; but there are some questions, which, though solved in theory, still depend on the results of physical experiment for perfecting their practical application. In fact, the elements of naval construction may be classed in two divisions:—those which are solely dependent on known laws of nature; and those, of which the solution resolves itself into laws which are yet imperfectly developed.

The first division embraces by far the greater part of those principles, on which the most essential properties of ships depend; and it may now be said, that the principal difficulties of these are surmounted, and are familiar to the naval architect: these are, alone, sufficient to enable a constructor to ensure the attainment of a certain and considerable degree of excellency to his ship; to give it a preponderance of any peculiar property; to discover the causes of any bad quality, and to obviate its injurious tendency, by an appropriate remedy. In fact, they are enough to "direct and limit the variations that may safely be made in the models at present in use, and guide him in the draught of new ones, suited to those changes in the force and magnitude of the several rates of vessels which

are continually making in the strife between the nations of the civilized world."[1] Should the science of naval architecture never make further progress than this, it has evidently arrived at a state of perfection, that will enable the pursuer of it, to keep pace with the wants of mankind.

The elements which may be classed in the second division consist, almost entirely, of those which are dependent, in a greater or less degree, on a knowledge of the nature and laws of elastic and non-elastic fluids: this is a question which has hitherto baffled alike the researches of the mathematician and the experimentalist; but, from the analogy of discoveries in other sciences, we may safely assert, that even its difficulties must be eventually surmounted by the patience and labour of the inductive philosopher. Not that the perfect solution of the problem is really of the importance to naval architecture which it is often asserted to be, and which the apparent intimate connexion of the science with the knowledge of fluids would sanction the belief in; for, of the elements of the construction of ships which appear wholly to depend on this knowledge, some are restricted by considerations which are quite foreign to its application; and though it may be a desideratum, in the determination of other elements, the difficulties which arise from the want of it, only require to be fully known and understood, to be, if not absolutely theoretically solved, at least, from the collection of facts, from experiment, and from analogy, so far overcome, as to leave nothing to be desired to complete their practical utility.

The form of a ship's body need not necessarily remain imperfect, because the curve of the solid of least resistance is unknown; since enough has resulted from the consideration of the nature of that solid, to prove that, however it might possibly be applicable to the navigation of smooth waters, the perfect solution of the problem could only be generally desirable to the naval architect as contributing to the theoretic perfection of the science, and would add but little to its practical utility, in its application to vessels which must encounter the tremendous powers of the elements, in the open seas; where experience must hourly show, that a ship constructed with the bow and form which is recognised as, at least nearly, approximating to the solid of least resistance, would

be unable to withstand the violence of the shocks of the motion of pitching, or of the waves; or, could she do so, would necessarily lose, by the additional resistance resulting from greater immersion, every advantage which might otherwise be anticipated. Neither can the exact position of the greatest section be a question of theoretic niceties, when the great capacity, and the adjustments of form, necessary to the exigencies of modern warfare, and the advanced state of navigation are considered, which not only require a ship to be effective in all the *materiel*, and for all the purposes, of war, when first from the hands of the architect, but to be equally so, after long periods have elapsed, and seas have been navigated. On the other hand, the comparative fulness of the fore and after bodies, the position, rake, and proportion of the masts, the adjustment and shape of the sails, the bracing of the yards, and many other questions intimately connected with the resistance of fluids, may, and will eventually, be correctly determined by comparison, experiment, and induction, guided by the knowledge of those principles of science which are involved in them; and without such knowledge, to enable us to certify the correctness of the conclusions which may be drawn, both experiment and comparison must be as useless to this, as, under similar circumstances, they would prove to any other branch of art.

Unfortunately, the preliminary studies of the naval architect, being principally mathematical, are so uninviting, and the pursuit of them is so laborious, that but few either can or will be at the pains to investigate their final utility; and as chance on some few occasions, inductions from a tedious experience on others, and more frequently the results of observations on ships built by men of science, may have produced good ships: the question is frequently too hastily decided, that, as ships possessing more than an average of good qualities have been produced without scientific study, therefore science cannot be available to the advancement of naval architecture. This, however, is not the fair result of the inquiry. The following quotation, from a very able paper on the "Theory of Ships," in a contemporary foreign periodical,[1] may strengthen this assertion, as the writer of the article is evidently well acquainted with his subject, and his opinion is therefore propor-

[1] Art. I., No. 3, American Quarterly Review.

tionately entitled to respect:—"Such, in truth, is the value of scientific inquiry, in this important branch of the useful arts, that those nations who have been most ready to adopt, in practice, the suggestions of science, have uniformly possessed ships the best suited for sailing and fighting, and the least liable to the dangers of the sea. Of this we have a most marked illustration, in the long contest for naval supremacy between France and England; the former nation having, from the close of the war of 1756, nearly down to that of the American war, baffled the fleets of England, and reaped all the advantages which would have flowed from actual victories, by the superiority of their ships in speed, and readiness of manœuvre; nor was this advantage lost, except by an entire change in the system of naval tactics, which diminished, for the moment, the importance of those qualities, and brought into play the more practised seaman-ship of the English. Throughout this period, we constantly find the French, after doubtful engagements, in which the apparent honour rather inclined to the side of their enemy, striking the severest blows upon the British colonies and commerce; and it appears now to be admitted, that, had the new tactics been fully understood and anticipated, and been met with a corresponding change of disposition, the advantages they derived from the structure of their vessels might still have been maintained."

"The Spaniards imitated the French, in the application of science to their naval affairs; and thus, in the wars of the French Revolution, their ships were remarkable for a combination of all the good qualities both of French and English naval architecture, of which the most remarkable instance is to be found in the Santissima Trinidada, a ship of four decks, uniting vast force to speed and stability, and built at a time when the French had almost abandoned, in despair of success, the construction of ships even of three decks; and when English ships of the second rate were so deficient in the necessary qualities, as to be by no means a fair match for the larger class of French two-decked ships, under equal circumstances of crew and officers."

Although these remarks exaggerate the advantages obtained by the French, we must undoubtedly admit that there were many instances in which the excellencies of their ships enabled

them to avoid engagements where disadvantageous to their interests, and greatly to annoy our colonies and commerce. The inferiority of the qualities of our ships, was also much complained of by many of our naval commanders. In a letter from Sir George (afterwards Lord) Rodney, dated May 31st, 1780, to Mr. Stephens, the Secretary of the Admiralty, is a passage which proves, in a remarkable degree, the truth of the above statement. "Nothing could induce them" (the French fleet) "to risk a general action, though it was in their power daily. They made, at different times, motions which indicated a desire of engaging, but their resolution failed them when they drew near; and *as they sailed far better than his Majesty's fleet*, they with ease could gain what distance they pleased to windward."

The following remarks extracted from a late article in the Quarterly Review, on "De Roos's Personal Narrative in America," appear so little to meet the question of the advantages to be derived from the application of science to naval architecture, and, in our opinion, are so much at variance with the best and dearest interests of our country, that we cannot refrain from offering some observations on them.

It is remarked, in this article,—"Much has been said respecting the application of abstract mathematical science to naval architecture; and long and laborious calculations have been made, to obtain those fine flowing lines, on which the stability and velocity of a ship are supposed to depend. With all due deference to such names as Bouguer, Bernouilli, Euler, and Don George Juan, while we admire the ingenuity of their theory, it will be seen that, with the exception of the last, they had little acquaintance with the practical effects of the action of an agitated sea on a ship. We cannot think there is so much art or mystery in the craft of ship-building, that is to say, in the construction of a ship's hull, as is generally supposed. The recent trials of what was called the 'experimental squadron,' have, among other things, tended to confirm us in this opinion. When we find two Captains in the Navy building ships, without the smallest pretensions to science, and one of them, at least, unable to draw a draught; and find Sir Robert Seppings building, not from science, but observation and experience—when we see those built after draughts prepared by Professor Inman, on scientific

principles (and no one disputes the extent of his science), and when it is found on trial, that their respective qualities are so nearly balanced, that every one proclaims his own the best, and the Admiral who accompanied them will not decide—we confess that we see no great reason for asserting the superiority of science over common sense and practical observation. When we recollect, too, that the late Sir William Rule, who, to use a homely expression, worked only by the rule of thumb, planned and built the Caledonia—a ship which, for beauty, strength, stability, stowage of provisions, birthing the men, quick sailing, and easy working; in short, for every practical good quality, has probably not her equal in the world—we must hesitate before we assign the palm to abstract science. * * * * *

"If the result of the trial-ships, to which we have alluded, should not be deemed sufficient to carry us to this conclusion, the case of the Barham will, we think, decide it. This ship was one of those seventy-fours to which a gallant Admiral facetiously gave the name of the 'Forty Thieves,' being built of green timber, in merchant yards, but on what was esteemed as a good model. She has recently been cut down from a two-decker to a frigate; of course, by the removal of a deck and upper works, and of about twenty of her guns, she has risen in the water, and presented an entirely new line of floatation, some three feet lower than before. Here, then, her bearing on the water is totally changed from that line which was calculated to be the only true one for stability and fast sailing; nor is this all: this hull, so reduced, and so much lighter than before, retains her original masts and yards, the former of which are, of course, about *ten feet higher* out of the *housing*, or above the deck, than when she was a seventy-four, and her lower sails deeper by ten feet than before—yet, with all these changes, which, we think, it would be difficult to ascribe to any result of mathematical principles, her sailing, and all other qualities, are reported to be essentially improved. * * * * * *

"The French ships are generally acknowledged to excel ours in the beautiful lines of their hulls, and to beat us on most points of sailing; and we have very often endeavoured to imitate them, by building on the same lines, but they have rarely answered the good qualities of the parent-ship. Nay, more; it is a common observation, that, if two ships be built from the

same draught, with the same scantlings, and by the same builder, their sailing qualities are never alike. To what, we ask, can this be owing, but to the different disposition of the masts, yards, sails, ballast, trim, &c., and to the difference of skill in the commander?"

The opinion expressed in the commencement of this quotation is evidently founded on a mistaken notion of the manner of the application of science to Naval Architecture, and, therefore, although the names of some of the principal writers are freely quoted, and their works are mentioned, it is doubtful if they have received the study and attention which was essentially requisite to authorise so sweeping a sentence against their practical utility. It is true, Don George Juan is the only author among those mentioned who was acquainted with the "practical effects of the action of an agitated sea on a ship;" but instead of the possession of this knowledge having convinced him that science was not available to the "construction of a ship's hull," we find that, of all writers on "Naval Architecture," he has been the most persevering, and has probably, more than any other, deduced from "abstract mathematical science," and "long and laborious calculations," principles useful alike to the naval architect and to the navigator.

With regard to the recent experimental trials, and the use which is made in this article of the results of them, it is much to be doubted whether the results so obtained can be depended upon, and whether, by the means of such experimental cruises, any correct character of the ships which composed the squadrons could be obtained. But this is a question of too voluminous a nature to be decided here; however, from a personal observation, and considerable knowledge of those trials, we have not the slightest hesitation in saying, that the characters which several of the ships that composed the last squadron, will bear in the navy, after they have been on various stations, and under various commanders, will differ most materially from those with which they, according to public rumour, returned from the experimental cruises. But to return to the quotation. Surely, "abstract mathematical science" must be applicable to the purposes of naval construction, if Professor Inman, a man who has only studied the application of science to naval architecture, because it became, by circumstances, a

branch of his duty, has been enabled to produce a vessel constructed on "scientific principles," which could compete with, in the opinion of all, and excel, in the judgment of some, those designed by two as able and intelligent officers as the Navy can produce, and who have confessedly made the subject of the construction and management of ships, the principal pursuit of their lives: and, with ships constructed by a man of such high, and deserved, eminence in his profession, as Sir Robert Seppings; whether the knowledge of principles by which he is guided, be the result of abstract study, or of "observation and experience." And, with regard to the mere mechanical, although professional, operation of "drawing a draught," we can positively say the Reverend Professor is as incapable of performing it as either of these gentlemen may be.

With regard to the Caledonia, it may be observed, that the opinions expressed in the quotation, of the acquirements of her constructor, vary considerably from the statement in the first article of this Number, containing a character of Sir William Rule, from the pen of a personal acquaintance; besides, a man holding a situation of authority has at his command the talents of all beneath him, and, therefore, even had Sir William Rule been so unfit to fill the situation of a constructor of the British Navy, as only working by the "rule of thumb" would infer, he had an ample resource in the talents of M. Barrallier and his son, who were both, at the time, his subordinates.

The author's remarks in the succeeding paragraph, on the management and trim of a ship, are extremely good, but he will find the same ideas in the works of every writer on naval architecture. Chapman expressly says, that "a ship of the best form will not show its good qualities, except it is at the same time well rigged, well stowed, and well worked by those who command it."

The case of the Barham, which is brought forward as a decisive argument against the application of science, is indeed a convincing proof how much a knowledge of the correct principles on which the qualities of a ship depend, may become available when any great alterations are at once proposed to be made, from that which custom has established, and which has, though by slow and uncertain steps only, been brought to a comparative perfection. This ship is the first, on which the

attempt has eminently succeeded of reducing a vessel to an inferior class by cutting down a deck; and this, merely because, hitherto, the alteration has always been made under the same error, with which the author of the quotation labours, when he expresses his astonishment that the ship, as a frigate, should bear masts ten feet higher from the deck than when she was a seventy-four. The error is, in the supposition that the masts and sails depend on the classification of the ship, and not on her relative dimensions; and also, the wonder at her increase of good qualities, from all these changes, arises from the mistaken notion that a constructor builds a ship with a view to absolute perfection, while the fact is, all he can attempt must be relatively to the necessities and exigencies of the class to which she belongs. Again, so far from the Barham's bearing in the water being totally changed from "the only true one for stability and fast sailing,"—her stability must necessarily be increased very considerably by the removal of such a mass of top-hamper, and is very triflingly diminished by her new line of floatation being lower than before; therefore, she is enabled to carry, as a frigate, more sail than she could possibly do as a line-of-battle ship; and, while the propelling force is by this means increased, the resistance she opposed to motion is diminished by her rising in the water. Nay, had the Barham, instead of her having her ballast reduced more than one half, when she was made a frigate, retained her original proportion, she would have required even larger masts. In fact, in pursuance of the principle, were she again to be reduced to a corvette, she would require still larger masts, and her stability and velocity would be further improved. The reducing a ship to an inferior class amounts to this, that she gains the advantage of the power derived from the relative dimensions of the large ship, combined, by her rising out of the water, with an approximation to the advantages of the form of the body of the small one.

The observations on the perfection of French ships militate strangely with the progress and tendency of the rest of the argument, as those ships are most decidedly the results of the application of science to naval architecture; while the fact that our builders could not even imitate them, so as to make the imitation equal to the parent ship, only proves, that not being aware of the principles of their construction, they were unable

to make the *alterations* which were requisite to fit them for the differences of the arrangements and materiel of the two services. For the concluding observation of the quotation, it is utterly impossible "If two ships be built from the same draught, with the same scantlings, and by the same builder," that their qualities can be the same, with a difference of "disposition of the masts, yards, sails, ballast, trim, &c., and a difference in the skill of the commander."

There is another passage which must be quoted. The author, after his observations of the effect of the position of the masts, cut of the sails, &c., on the qualities of a ship, says, "Let but a ship be built with a full round bow, to meet a head-sea, with her extreme breadth carried well forward, diminishing in a regular curvature to the stern, to let the water she displaces pass freely aft, as nature has provided in the shape of fish and water-fowl, and not to be immersed too deep in the water; and such a hull, with the other points above enumerated, managed as they ought to be, will compensate the want of lines and curves deduced from mathematical calculations." Daily experience shows that good and effective ships are sometimes produced solely from observation of this nature, but at the same time here is no surety of success, no knowledge which will authorise any change being made from what has been done, or if a change be attempted, there is no certainty that its effect will be that proposed, or that its success may not be more than compensated by an attendant evil. Nay, among the requisites mentioned above, there is one, that of the ships not being "immersed too deep in the water," which cannot possibly be assured by any observation or experience, but must absolutely be the result of laborious calculations founded on the principles of science. The many failures in cutting down ships previously to the case of the Barham may be instanced in confirmation of these remarks. And though an experience founded on observation may be able to avoid great errors in tracks already beaten, nothing but a knowledge of principle, which in fact is science, can ensure successful deviations from that track.

The motion of pitching, which has been before mentioned in speaking of the causes which must govern the shape of the bow of the vessel, is generally the most violent action to which a ship is subjected, and the most injurious, both to the connexion

between the parts of her structure, and to the velocity of her course. It is the longitudinal motion, caused by the unequal support afforded to the body by the waves, as the vessel passes over them, when on a wind, and by the consequently constant efforts of the gravity of the body to recover the state of equilibrium which, before the commencement of the motion, had existed between it and the buoyancy of the fluid. The motion will continue as long as the vessel remains in the same course, and the inequality of the surface of the water continues; but when the direction of the wind on the vessel becomes such, that it can act in conjunction with the gravity of the vessel, and in constant opposition to its oscillations, the motion will cease. For these causes, the pitching motion can only exist in any violence when a vessel is on a wind: then, its force will depend on the degree of inequality of the surface of the water, on the quickness or slowness of the succession of the waves, on the direction in which they strike the bow of the vessel, and on the shape of the bow, as it influences the degree of violence with which it meets the water, and the resistance it opposes to submersion.

The least injurious action of pitching, is when the state of the sea is such, that the motion of the ship may be supposed to take place round a line passing through its centre of gravity, as a fixed axis of rotation; for then the motion may be compared to the oscillations of a pendulum, and its violence may, in a great degree, be regulated, by either increasing or diminishing the length of the isocronal pendulum, according as the state of the sea appears to require the oscillations to be made in longer or shorter periods: these effects may be severally produced, by removing weights further from the axis of rotation, or by approaching them nearer to it; that is, by increasing or diminishing the moments of inertia.

But it is, as has before been said, only in some states of the sea that the pitching motion in a vessel can be compared to the oscillations of a body round a fixed axis of rotation, passing through its centre of gravity, and where the moments of inertia, of both the fore and after bodies, oppose the motion: for, under many of the circumstances of heavy seas, though, at the commencement of the motion, the axis of rotation may pass through the centre of gravity of the ship, it will pass abaft it,

as the wave passes aft; in this case, therefore, the moment of inertia of the body before the axis of rotation, which, when this axis passed through the centre of gravity, was equal to the sum of the particles in that body multiplied by the squares of their distances from the axis of rotation, will become, at any instant afterwards, when the axis of rotation shall have passed abaft the centre of gravity, increased, by the difference between this quantity, and the sum of the products of the particles in the then fore body, by the squares of their distances from the new axis of rotation; consequently, the moment of inertia of the fore body will be constantly increasing until the end of the motion; while the moment of inertia of the part abaft the axis of rotation, will be constantly diminishing, under the same limits. That is, the force which has an injurious effect on the violence of the pitching increases, while that which diminishes its violence decreases. As the direction of the motion of the waves is opposed to that of the vessel, the momentum with which the bow of the ship will meet the sea at the expiration of the motion, is equal to the sum of the momenta of the bow and the sea; and this impulse is often so great in practice, as to be sufficient completely to check, for several seconds, the motion of the vessel in her course. A frequent recurrence of these shocks must, therefore, not only be extremely injurious to the strength of the fabric of the ship, but must, of course, materially affect her progress through the water, and may even, in some situations, compromise her safety, from the increased liability of shipping seas, especially in deep-waisted vessels; and also, unless a ship can contend with advantage against a head sea, her chance of escaping the danger of a lee shore must be considerably diminished; as there, her safety would, in a great measure, depend on the possession of that property: for, on the tack in which she would run under the seas, the force of the waves, in driving her to leeward, might more than compensate for her increase of velocity through the water.

From these considerations it is evident, that every change which can be made to diminish the extreme violence of this motion, when it takes place under the circumstances which have been described, either by lessening the moment of inertia of the fore part of the ship, or by giving that part the form which will the most conduce to render its impact with the water

more gradual, must be advantageous, with respect to the velocity, to the preservation of the strength of the ship, and even to increasing the safety of the crew. But, since the bow of a ship is subjected to shocks of such a violent nature, it must necessarily consist of a vast combination of materials, to ensure an adequate power of resistance; great care, however, should be taken, that there be not more weight than this condition renders necessary. But the principal source from which advantage might be derived, would be from moving the fore-mast, with the weights dependent on it, further aft; and it will be attempted to prove, by pointing out the various forces which act on a ship when in motion, and the several considerations such a measure would involve, that it is not impracticable; and that it would even be attended with other advantages.

When a ship is under sail, there are two forces acting on it: the one, the force of the wind on the sails, to propel the ship; and the other, the resistance the water opposes to its motion: these forces, immediately the ship has acquired the velocity due to the strength of the wind, are equal, and, as is the case with all forces, may each be reasoned on as if acting on only one point of the surface over which its effect is spread: this point is that in which, if the whole force were to be concentrated, its effect would be the same as when dispersed over the whole area; it is usual to call these "resultants of forces," and the spots on which they are supposed to act, "centres of effort." From what has been before said, the resultant of the force of the wind on the sails, and the resultant of the force of the water on the hull, are equal: the one acting on the weather side of the ship, in the direction in which the force of the wind resolves itself; and the other opposed to it, acting on the lee-side, in the direction in which the force of the water resolves itself: and their effect is, of course, in proportion to their distance from the centre of gravity. If they are equally distant, they will destroy each other, and the ship will remain at rest with respect to the line of its course; if the resultant of the resistance of the water pass before the resultant of the wind, the ship will turn to the wind; and of course, if the resultant of the wind pass before that of the water, the effect will be the contrary: in either case, it will be necessary to equalize the forces, by the action of the water on the rudder, on its lee-side,

to bring the resultant of the water more aft, and on its weather side, to destroy a part of the effect of the wind. This is the principle of the action of the wind on the sails, and of the water on the hull, with respect to the course of the ship through the water; and it is on these considerations only, that the various changes can be regulated, which it may from time to time be necessary to make, in the trim either of the sails or of the ship: and, of course, the accurate determination of the positions and directions of these two forces is a point of great importance in naval architecture. The position of the centre of effort of the wind on the sails may be found under certain reservations; and, that being known, enough is determined to lead to correct conclusions on the other circumstances attendant on the subject.

In order to find the distance of the centre of effort of the wind on the sails, before the centre of gravity of the ship, the moment of each sail is found, by multiplying its area by the horizontal distance of its centre of gravity, from that of the ship; the sum of the negative moments, or of those abaft the centre of gravity of the ship, is then subtracted from the sum of the positive moments, or those before the centre of gravity; the remainder is then divided by the whole area of sail, and the result gives the required distance. The situation of this point, with respect to the length of the vessel, must determine, in a considerable degree, the position of the masts; for experience has proved, that it is among the most essentially requisite good qualities of a ship that she shall carry a weather helm.

It does not, at first, appear evident why the rudder should have more effect on the ship when it meets the water on one side of the middle line, than it has when put to an equal angle on the other side: the reason has, however, been partially explained, from the consideration of the direction of the motion of a ship through the water, by several writers on naval architecture. Don Juan has been the most explicit; the reasoning he pursues is this: as a great portion of the force of the wind, in all oblique courses, tends to drive the ship bodily to leeward; and as this effect cannot, by any means, be wholly destroyed, the true course of the ship is not in the direction of its own middle line, but in that of a line passing from the lee-bow to the weather-quarter, parallel to the ship's wake; and, he supposes, that the fluid meets the rudder in the direction of this

line of lee-way, both on the lee and weather side of the ship; and that, therefore, when the helm is a-weather, the angle of incidence of the fluid on the rudder is equal to the *sum* of the angle of lee-way, and the angle made by the direction of the rudder with the middle line of the ship: while, when the helm is a-lee, the angle of incidence is only equal to the *difference* between these two angles; and therefore, of course, when they are equal to each other, this difference vanishes, and all action of the water on the rudder ceases: and this, under Don Juan's suppositions, would occur when the rudder was in the direction of the line of lee-way; and as, of course, the most advantageous general position for the rudder is that in which, by offering no obstacle to the passage of the water, it offers no resistance to the velocity of the ship, and yet, by the least variation from this inactive position, might be brought to act effectively on her; it follows, either that Don Juan's reasoning is incorrect, or that the advantageous general position of the helm should be a-lee. But experience proves, that, with the helm a-lee, the rudder would not have the effect on the ship which has been described: therefore, although Don Juan's reasoning shows the main principle of the greater effect of the rudder when to leeward, than when to an equal angle to windward, of the middle line of the ship, it is insufficient to account for the fact, that the general position of the helm should be a-weather; indeed, as has been shown, it proves that it should be a-lee; which arises from the erroneous assumption, that the fluid meets the rudder, on the weather side of the ship, in the direction of the line of lee-way. Now, when a ship is on a wind, the particles of water which successively come in contact with the lee-bow, in consequence of her motion in the direction of her course, are some of them forced on in that direction; others escape laterally, in the direction of tangents to the various points of the curve of the bow; while others are forced on before the bow, in every direction between these limits: and the whole, in their passage, communicate a part of their motion to the several particles of fluid with which they come in contact; and those, in the same manner, to others; and, as the action of the bow on the fluid is constant, these effects will be constant; and the whole of the particles that escape laterally will acquire a constant motion, in a direction making an angle

with the middle line of the ship, which will be greater or less, according to the degree of fulness of the lee-bow of the ship. And, whatever other effects may be produced on the particles of water by the passage of the vessel through them, this motion will operate, in a greater or less degree, on those effects. Now, although, in consequence of the difference in the bulk of the two extremities of the vessel, the particles of water will acquire motions, in various directions, to fill the vacuum round the lee-side of the stern, the principal action will, both on account of the accumulation at the bows, and the velocity of the vessel, take place from forward; and the particles, in their passage, will necessarily partake of the motion of those which they replace, in a greater or less degree, in proportion to the causes which operated to create that motion. Therefore, the particles of fluid will leave the stern of the vessel in a direction compounded of the two motions; one parallel to the middle line of the ship, and the other in the direction of the mean tangent of the bow: that is, they will leave the stern in a direction making an angle with the line of the ship's course, greater than the angle made by the middle line of the ship with that line; and consequently, the inactive position of the rudder will be, when it is in this direction, that is when the helm is rather a-weather; the degree will depend on the fulness of the bow, the fineness of the after part, and on the angle the ship's course makes with her middle line. And this position should be the theoretic limit of the degree of weather helm a ship should carry, as in any other position, there must be a force acting on the rudder which must increase the resistance the ship experiences in her passage through the water. A practical confirmation of the correctness of this principle, and of the fact that this position of the rudder is a-lee of the ship, may be drawn from the common observation, that when a ship is in good trim, the helm, being a-weather, has a very perceptible tremulous motion, which must arise from the rudder's being in a position, in which it is not acted upon on either side by any constant force.

This method of considering the direction of the flow of the water to the rudder, considerably diminishes the estimate of the excess of its effect on the lee-side of the rudder, over that on the weather. But there are several other considerations which

operate in increasing the effect of the weather helm. From the direction in which the water flows past the ship, there will be a much greater reduction of pressure on the weather-side of the rudder when the helm is to windward, and therefore a greater positive pressure on its lee-side to turn the ship, than will occur under the opposite circumstances, or when the helm is a-lee. Also, the broken and disturbed state of the water on the after part of the weather-side of the ship, and the consequent various degrees of resistance it opposes, must lessen its effect when the helm is a-lee.

It has been said to be proved by practice, that ships which carry lee helms cannot be weatherly, that is, will fall faster to leeward than those which carry weather helms: but though the fact may be correct, the reason assigned, is in some degree mistaking the effect for the cause. It has before been said, that a part of the force of the wind acts, in driving a ship bodily to leeward, of course its effect will be greater or less in proportion to the lateral resistance opposed to it, and the ship which opposes less lateral, and greater longitudinal, resistance to the water than another, will, in the same period of time, have fallen furthest to leeward, and the line of her course will have made a larger angle with her middle line; by which the effect of the water on the after part of the lee-side is increased, while that on the fore part, both of the lee and weather sides, is diminished; and the helm must consequently be kept less a-weather. A practical proof of the correctness of this reasoning may be drawn from the practice of the merchant vessels, which are generally, from form, more leewardly than men of war; they have their [1] foremast placed much nearer the centre of the ship than is usual in sharper and finer-formed bodies; this has evidently arisen from the operation of the cause above-mentioned, which has shown that they require the resultant of the resistance of the wind on the sails, to be proportionately further aft, to ensure their carrying a weather-helm. From this reasoning it is evident that, under some circumstances, it may be the leewardliness of the ship which causes her to carry a lee-helm, and that when such is the case, the

[1] The Comet, a bomb, a class of vessel approximating, in form, to a merchant ship, was sold out of the service: her fore-mast was then removed four feet aft, by which she was much improved.

defect might be remedied, not only by the usual methods of placing the masts further aft and altering the draught of water, but by increasing the *lateral* resistance by the addition of false keel, or by greater depth in the water.

There is another disadvantage which arises from a ship's carrying a lee-helm, which is, that then the action of the water on the weather-side of the rudder, acts in conjunction with the force of the wind, in forcing the ship bodily to leeward; while, on the contrary, when the helm is a-weather, the action of the water on the rudder, is in opposition to the force of the wind.

Having now endeavoured to point out, in what the necessity consists that a ship should carry a weather-helm under all circumstances, and to explain the principles by which the position of the helm is governed, it next remains to consider in what manner this position may be affected, when the ship is under sail: this is the more necessary, because there are occasions on which ships that generally carry good helms, will carry them a-lee; it therefore also remains to examine, whether this defect might not either be removed or ameliorated.

The ardency of a ship, which is her tendency to fly to the wind, depends, as has been explained, on the relative positions of the resultant of the effort of the wind on the sails, and the resultant of the resistance of the water on the hull. A consideration of the effects produced on these forces, when a ship is under way, will lead to the object of our inquiry.

When a body passes through a fluid, it causes an accumulation of the fluid to take place towards its foremost extremity, and a depression of the fluid towards the opposite. The degree of this accumulation and depression, will, of course, depend on the velocity with which the body passes through the fluid; and its increase must necessarily have a great effect in drawing the position of the resultant of the water further forward; therefore, from this cause, a ship becomes more ardent as her velocity is increased. Also, as the ship inclines by the force of the wind, a greater surface of the lee bow is immersed, though, from the fulness of its shape, the angle of incidence of the water on it does not undergo much alteration, while the effect of the water on the after part of the lee-side is considerably decreased, in consequence of the much greater diminution of its angle of incidence, arising from the sharpness of the

after body. It appears, then, that the inclination increases the ardency, by drawing the resultant of the water forward.

The position of the centre of effort of wind on the sails, is calculated under the supposition that the sails are plane surfaces, and equally disposed with regard to the longitudinal axis of the ship; but when a ship is on a wind, as the force of the wind acts in a direction oblique to the surface of the sails, a greater proportion of the sail is carried to leeward of this axis, and the whole sail assumes a curved surface; the curvature of which increases from the weather to the lee-side: from these circumstances, the centre of effort is, in fact, carried gradually further aft as the action of the wind takes place on the sails. Also, as the force of the wind inclines the ship, its centre of effort is carried, by the inclination, over to the lee-side, and by this, as well as by the effect produced on the resultant of the water, which has been before mentioned, the distance between them is further increased. It therefore appears that the quantity and disposition of the sail set remaining the same, the ardency will increase as the force of the wind increases, and of course diminish as that force diminishes; but as it is found in practice that ships very generally require their helms a-lee in light winds, although it is evident that the several circumstances which have been mentioned as creating the tendency of ardency, must still exist in a small degree; it would appear, that the ardency must increase and decrease in a faster ratio than the force of the wind; now, as the direct and lateral resistances are as the squares of their respective velocities, it is evident that the lateral resistance will diminish in a faster ratio than the direct, and that, consequently, as the wind decreases, the angle of lee-way, or of the ship's course, will be increased, which it has before been proved, will draw the resultant of the water aft, and diminish the ardency; therefore the increase and diminution of the ardency of a ship, will be in proportion to the difference of the ratios of increase and decrease of the direct and lateral resistances.

From the causes which have been assigned for a ship's carrying a lee-helm in light winds, it is evident the defect may be lessened by all those means, of trimming the sails or the ship, which have been mentioned as increasing the distance of the resultant of the water before the centre of effort of the wind.

But when a ship's carrying a lee-helm is occasioned, as it sometimes is, by the state of the sea; the waves of which, strike the ship on the weather-bow, and in their passage cause a great immersion of the lee-quarter, any attempt to bring the resultant of the water forward, would, from the consequent greater immersion of the bow, and the necessary addition to the momentum, increase the effect of the impulse. The evil may be lessened by diminishing the quantity of head-sail, which will both bring the centre of effort of the wind aft, and ease the violence of the pitching; and also, if the inclination of the ship were increased, that, by increasing the effect of the water on the lee-bow, and diminishing its effect on the lee-quarter, might also, in some cases, prove advantageous.

In heavy weather, ships under a small quantity of sail, very generally carry slack helms, partly in consequence of the position of the centre of effort of that sail, and partly owing to the state of the sea. Under these circumstances, it is generally impossible to carry enough after-sail to alter the defect; and to trim by the head, would only increase it, on account of increasing the pitching: there is therefore no other remedy than may arise from such an original disposition of the masts, as would render the power of creating a balance between the effects of the sails more easy. But, of course, before making any alteration in the position of the masts, great caution is necessary, for possibly, one of the first requisites in a ship is, that she should work quickly, which quality depends on the proportion of sail before and abaft the axis of rotation, and not on the position of the centre of effort of the whole surface of the sail. Therefore no alterations can be made in the position of the centre of effort of all the sails, or in the position of the masts, unless due consideration is given to the effect they may have on these proportions.

It may now be necessary to observe, that a ship may, on some occasions, be too ardent. In addition to the alterations which will suggest themselves in this case, from what has been already said, it may be observed; that as the curvature of the sails, and the inclination of the ship, both tend to increase the ardency, it may be diminished by taking in sail, especially those which from their greater breadth assume a greater degree of curvature.

It is sometimes objected by practical men, that trimming a ship according to the principles laid down by theory, has not the effect which was to be expected; but this often arises from an ignorance of the necessary degree of trimming, or from a mistaken notion of the effect which a certain degree will produce. In order, in some measure, to obviate this difficulty, the following table is given, it contains the weight which will be necessary to be moved a distance of forty feet, either aft or forward, to produce an alteration of one foot in the trim of a ship. The length and breadth are given in the table, merely as being more sure data for the comparison of size, than the class of the vessel, or the number of guns.

Class of Vessel, and Number of Guns.		Length.	Breadth.	Weight to be moved a Distance of Forty Feet.
		Feet.	Feet.	Tons.
1st rate	120	205,25	54,50	112
2d ..	84	192,25	51,44	90
4th ..	60	174,00	43,67	58
5th ..	46	159,70	40,50	38
6th ..	28	120,20	33.67	22
Sloop ..	18	111,25	30,50	14

If any other alteration in the trim be desired, it may be deduced from the results given in the above table, by a simple proportion. A French writer on naval architecture, *Du Maitz de Goimpy*, has deduced, from experiment, the following average estimate of the effect produced on the resultant of the resistance of the water, by any difference made in the trim of the ship:—that an alteration of 18 inches in the draught of water will draw the resultant 12 inches nearer to that extremity of the vessel, of which the immersion is increased. And, since the effect produced on the centre of effort of the sails, by taking in, or setting, any sail, may be estimated in the manner described in the course of these remarks; the cause necessary to produce any desired effect, may be easily found. Another source of error may arise from the various rakes of the masts; from which the angle of incidence, and, consequently, the force of the wind, which is as some function of the sine of the angle of incidence, varies considerably for the sails of each mast; and, if the trim of the ship be altered, there must be a corresponding effect produced in this angle: by which the relative

proportions of the force of the wind on the several sails will be altered, as will also its total effect on all the sails.

Most of the writers on naval architecture have occupied themselves with the problem of determining the angle which should be formed by the yard with the keel, under the different circumstances of wind. Don Juan, whose highly scientific and thorough practical knowledge, entitle his opinions to more than common attention, on a subject in which the researches of theory require to be aided by the deductions from experiment, has determined these angles for a ship of 60 guns, and has also given some general rules to guide any variations from them. When this ship was close-hauled, with all sail set, he determined that the angle the yard should make with the keel should be 28°47′, and, with the wind on the quarter, 50°11′; but, when the wind was so high that but a small quantity of canvass could be set, these angles were respectively increased to 40°42′ and 56°21′. He also arrives at the general conclusion, "that, the greater the quantity of sail set, the less should be the angle made by the yard with the keel;" and also, as he makes the relation between the direct and lateral resistances enter into his investigations, "the sharper, and the more adapted for velocity a vessel is, the smaller should be the angle made by the yard with the keel." Consequently, frigates and smaller vessels should, under similar circumstances, have their yards sharper braced than line of battle ships; and again, "that the nearer the sails approach to plane surfaces, the less should this angle be."

According to the present positions of the masts of a ship, the sails on the fore-mast are, generally, not capable of being so sharply braced as those on the main-mast; but as theory and practice, as may be instanced in fore and aft-rigged vessels, concur in fixing the limits to which it would be desirable to brace the yards, within even what can generally be attained on the main yard, much of the force of the wind on the sails of the fore-mast must be lost; and as this less degree of bracing, common for the yards on the foremast, is found even to be necessary, in many of the ships, to enable them to carry their helm sufficiently a-weather; it would appear that the position of the fore-mast is too far forward, and that moving it aft would be advantageous; besides the good effect it would have, as has been shown, in diminishing the violence of the pitching motion.

The position of the fore-mast appears to have remained nearly the same as it was determined in the early part of the last century; while the reasons which then fixed it, at about one-ninth the length of the ship from the stem, have many of them ceased to exist. Our ships are now longer, and there is, consequently, room for the sails, without those of one mast being injurious to those on the other; the after parts of the hull above water are very considerably reduced, and do not, therefore, render so great a proportion of head-sail necessary to counterbalance the effect of the wind on them; the bodies of the ships are, from the increase of the dimensions, much finer abaft, and, consequently, the resultant of the resistance is further aft: from these considerations, and from the fact, that it is found that complaints are made of ships carrying lee-helms, it appears not improbable that the generality of our ships would be improved by an alteration in the position of their fore-masts.

The forms of our ships, and, indeed, those of some of the more modern French vessels of which we are possessed, have approximated more to that recommended by Chapman, and since his time adopted by the Swedes and Danes, than to that of the old French bodies, which were, for such a series of years, the chief guides of the English ship-builder. The marked characteristics of the old French body were, a flat floor, with a sharp, and, beneath the water, hollow, fore body, and a comparatively very full after body. The character of the Swedish construction is, the rising floor, full fore body, and extremely fine after body. The generality of English ships of the present day are built with the rising floor, and approximating more, towards the extremities, to the Swedish, than to the old French characteristics. It seems, therefore, but reasonable that the positions of the masts of our ships should partake of the principle which appears to have dictated the alteration in the form of their bodies. With this view, the following table has been formed of the positions of the masts of the vessels contained in Chapman's large work, of some of the present Swedish ships, of the several classes of English ships, and of several other vessels which have either some peculiarity in this feature of their construction, or are remarkable for an excess of any good or bad quality dependent on it. The other data in the table are necessary for completing the comparisons which may be made.

Ships' Names, and Number of Guns.		Length on the Load-water Line.	Distances of the Masts abaft the foremost Extremity of the Load-water-line.			Ratio of the Distances of the Masts from forward, to the Length of the Load-water-line.			Ratio of Difference of Draught of Water to the mean Draught of Water
			Fore-mast.	Main-mast.	Mizen-mast.	Fore-mast.	Main-mast.	Mizen-mast.	
		Feet.	Feet.	Feet.	Feet.				
Swedish Ships, from Chapman's large Work.	110	205,2	28,8	118,5	174,0	,1398	,579	,848	,094
	94	190,1	27,0	112,2	164,1	,1402	,580	,857	,085
	80	182,1	25,7	105,5	154,2	,1402	,578	,845	,089
	74	177,9	24,8	102,7	150,0	,1398	,576	,848	,083
	66	174,0	24,3	100,0	146,8	,1400	,578	,844	,082
	52	164,1	22,9	93,2	138,4	,1390	,569	,845	,103
	40	149,6	23,3	86,5	125,2	,1570	,580	,840	,100
	32	125,3	19,5	72,5	104,4	,1550	,578	,831	,093
	20	113,6	17,5	65,5	94,6	,1540	,578	,837	,142
Carl XIII. Swedish.	80	177,9	24,3	102,0	148,6	,1380	,578	,858	,108
Corvette, Swedish.	20	108,5	15,6	61,7	90,8	,1440	,570	,835	,120
The Chapman, Swed.		149,8	28,0	89,5	124,2	,187	,598	,835	,000
President, French.	46	159,5	24,0	87,5	132,2	,150	,550	,831	——
Comet, Bomb.		109,0	13,4	61,7	90,5	,123	,565	,831	,000
Comet, as altered.		109,0	17,4	61,7	90,5	,162	,565	,831	——
Pearl, Mr. Sainty	18	114,7	18,7	64,0	97,4	,163	,557	,850	——
Caledonia ..	120	205,25	25,0	113,0	171,7	,122	,552	,835	,057
Asia	84	192,25	22,3	109,0	160,2	,116	,568	,832	,053
Southampton	60	174,00	20,7	97,2	146,7	,119	,560	,845	,048
Seringapatam	46	159,7	21,2	85,6	132,3	,133	,535	,832	,076
Leda	46	151,0	18,8	85,3	128,7	,124	,565	,854	,089
Euryalus ..	42	146,0	17,7	82,2	123,8	,124	,563	,848	,104
Sapphire....	28	120,2	14,7	68,7	102,4	,122	,568	,850	,066
Orestes	18	111,25	14,5	64,7	97,4	,129	,573	,864	,060

From this table it will be seen, that the position of the fore-mast in the ships of different rates in his Majesty's service, is considerably more forward than in the Swedish ships; and, that in Chapman's experimental frigate, the Chapman, it is remarkably far aft. The Comet, as altered, and the Pearl, built by Mr. Sainty, are proofs of the practice, before alluded to, of the merchant builders; the alteration in the position of the mast of the Comet having taken place under the direction of Mr. Fearnall, a gentleman of high character for a knowledge of his profession.

The positions of the masts are given, in the table, in relation to the fore side of the rabbet; but, though this point has been adopted in compliance with the usually received custom, and to avoid the introduction of a feature which might have rendered comparisons more difficult, a more correct method would be, to estimate the station of the masts from a point K (Fig. 31) at a distance AK, from the foremost extremity of the load-water-line: such that, KP being drawn perpendicular to the load-water-line, it shall intersect AD, the foremost boundary of the longitudinal vertical section of the vessel, in such a manner that the resistance to angular motion, round an axis of rotation BC, passing through the centre of gravity of the vessel, shall be equal, for the triangles AKF and DFP; DP being the lower boundary of the false keel, produced.

The point K being determined for all ships, comparisons might be correctly made of the positions of the masts in vessels with the most dissimilar rakes of the stem; which feature, from its effect on the resultant of the resistance, must have a considerable influence on the positions of the masts, which cannot be expressed in distances estimated from any other point.

The following proof will show, that if BK be taken equal to the arithmetical mean between BA and CD, the point K will be determined sufficiently correctly for all practical purposes.

From D (Fig. 31), draw DV perpendicular to AB. Bisect KF and FP, in G and M, and draw AG and DM. Take AH $= \frac{2}{3}$ AG, and DN $= \frac{2}{3}$ DM: then H and N will be the respective centres of gravity of the triangles AKF and DPF. From H and N, draw HL and NO perpendicular to AB and CP.

Let AB $= a$, CD $= b$, AV $= a - b = c$, AK $= x$, AL $= \frac{2}{3}x$, and VD $= h$.

Then the resistance to rotation of the triangle AKF is proportional to the area $AKF \times BL = \frac{AK \,.\, KF}{2} \,.\, BL$.

$$\text{Now, } AK : KF :: AV : VD$$

$$\therefore KF = \frac{hx}{c}$$

$$\therefore \text{the resistance} = \frac{hx^2}{2c} \,.\, \left(a - \frac{2x}{3}\right)$$

In the same manner, the resistance of DFP is

$$= \text{area } DFP \,.\, CO$$

$$= \frac{DP \times PF}{2} \,.\, CO$$

$$PF : DP :: DV : AV$$

$$\therefore PF = \frac{h \,.\, \overline{c-x}}{c}$$

$$\text{Hence the resistance} = \frac{h \,.\, \overline{c-x}|^2}{2c} \,.\, \left(b + \tfrac{2}{3}\,\overline{c-x}\right)$$

and these resistances must be equal to each other.

$$\therefore x^2 \left(a - \frac{2x}{3}\right) = \overline{c-x}|^2 . (b + \tfrac{2}{3}\,\overline{c-x})$$

$$\tfrac{2}{3}\,(\overline{c-x}|^3 + x^3) = a x^2 - b \,.\, \overline{c-x}|^2$$

$$\tfrac{2}{3}\,(c^3 - 3c^2 x + 3 c x^2) = c x^2 + 2bcx - bc^2$$

$$c x^2 - 2c^2 x - 2bcx = -bc^2 - \tfrac{2}{3}c^3$$

$$x^2 - 2ax = -c\left(b + \frac{2c}{3}\right)$$

$$x = a - \sqrt{a^2 - \left(bc + \frac{2c^2}{3}\right)}$$

From which expression, if numbers be substituted for the several quantities, it will be seen that, assuming BK equal to the arithmetic mean between AB and CD, will be sufficiently correct.

PAPERS

ON

NAVAL ARCHITECTURE,

&c.

ART. XVII.—*Remarks on Steam Vessels; with a Notice of a Treatise on Navigation by Steam, by Captain Ross, K.S., R.N.*

THE authors of discoveries and inventions in science have happily little, in the present age, to complain of: so far from useful inventions being disregarded, there are few schemes, however speculative, which are not at least regarded with attention, and examined before they are rejected. Useful inventions are now hailed in all countries with enthusiasm; are protected by the laws, and are encouraged by patronage and rewards. While we admire the enlarged spirit of philosophy, which rejoices in the general advancement of knowledge, and in the general benefits resulting to the arts; which considers the world as the arena of its efforts, and the benefit of mankind as the object of its hopes; we would indulge in another feeling, not less honourable to man, who, by the law of nature, is a social being, with partial sympathies and local attachments; the feeling of especial love to country and particular regard for its interests. In the consideration of the general advantage of inventions to the useful arts, we would not damp our feelings of joy at their utility to the world, but we would concentrate them in our desires, that they may especially benefit our own country. We would go further; however brilliant a discovery might be, and however beneficial it might prove to the general interests of science, if other nations would receive greater relative advantage from its operation than our own, we

should, as Englishmen, receive its annunciation with sorrow, and mark its progress with deep regret.

When a discovery is made in a science, which promises to effect a practical improvement in some department of a nation's resources or operations, whether civil or military, it is not enough to show, abstractly, that the improvement is great and certain, in order to decide on the propriety of its adoption; it must be considered in respect to the relative advantage it confers on the nation compared with its advantages to other nations. As a general principle merely, dependent in practice on peculiarities of detail, if two nations, in the present state of any science, derive *unequal* advantages from its use, any improvement which would confer equal additional benefits to the two nations, would necessarily be disadvantageous to the nation deriving, previously, the greater benefit from its operation. For instance, supposing the relative naval power of England compared with that of any other nation to be represented by four to one, and that some improvement should take place in naval warfare which would confer equal benefits on the two nations, which might, in relation to previous power, be estimated by two, then the relative power of England to that of the other nation, after the adoption of the improvement, would be only as two to one: that is, the relative superiority of England would be diminished one-half.

In considering the effect of any improvement on the prosperity of a nation, this general principle should be always duly appreciated. The discoverer of any principle in science, or of its applicability to practical uses, is certainly not always, perhaps seldom, the best judge of the political expediency of its adoption; it is the part of the statesman to consider it in this point of view; to regard it in its ultimate bearings and relative effects on the national interests, and either to check or encourage its being carried into practice. The most enlarged view of the general bearings of the subject, with an extensive and minute acquaintance with all the interests to be affected, is necessary in order to decide with certainty on the expediency of the adoption of the invention. If it be objected, that when a statesman is convinced, that the change likely to be effected in the future operations of any department of the service by the

adoption of any invention, would be relatively disadvantageous to his country, he will be unable to prevent its adoption by other nations, to which it may be relatively advantageous; it may be shown by reference to experience, that nations are generally slow to adopt improvements which have originated in and been rejected by other nations; frequently too hastily deciding, that the invention was rejected from its want of practical utility, without due consideration of its merits: its adoption may require numerous arrangements, which the trouble of considering may prevent attending to; it may appear to require resources which a country may not afford; or it may be really so. Even where the previous rejection of an invention by one nation does not prevent or control other nations in its adoption, yet such a decision, founded on an extensive acquaintance with the subject, would, at least, prevent the unnecessary expense of arrangements, which might be required only as the consequence of their adoption by other nations. The same principle, however, leads to the prompt and effectual adoption of any improvement, which the exigencies or interests of a nation may require.

The vast extent of the British dominions, and their numerous important interests, render every change in naval affairs an object requiring the most particular attention, and demanding the most energetic measures. The naval force of England must be always considered in relation to its decided superiority over that of other nations; and in a future war it must be regarded as generally seeking engagements with the fleets of foreign powers. Under this consideration improvements in naval affairs must be chiefly regarded as conducing to advantage in the attack: a consideration highly gratifying to our national honour.

The history of naval affairs presents two great eras in its progress: the discovery of the properties of the magnet, with its use in the mariner's compass; and the introduction of cannon on board ships. The application of steam as the propelling power of vessels, is now producing another change in naval power, the extent of which we cannot yet correctly estimate. That it is effecting a very decided change in naval affairs, affecting not only the commercial navy, but ships of war, and

which will influence, in a very great degree, future engagements, and even decide their fate, we have reason to believe. The relative power of different nations will be materially changed by the alterations in naval warfare which this introduction will occasion, requiring resources in many respects differing widely from those necessary for the construction, equipment, and management of sailing vessels. The seamanship and tactics peculiar to this kind of vessel will render the experience of seamen, long inured to the dangers and difficulties of sailing vessels, although not less necessary, yet in degree less important than it is at present: an equal number of good seamen will not be necessary in the equipment of a navy composed of a great proportion of steam-vessels, as in a navy composed of sailing vessels. In the present state of naval affairs, those nations alone which possess extensive commercial navies can equip large fleets on the sudden commencement of a war; and although such a resource will be always absolutely necessary for the equipment and support of extensive fleets,—an advantage which England happily possesses, and which will continue to render her naval power vastly superior to that of all other nations,—yet, as steam vessels gradually form a greater proportion of naval force, so far will it tend to reduce the magnitude of this advantage; at least, it will enable nations, possessing but small resources in this respect, to support a navy which, in many ways, may be formidable. Equal skill will be necessary in steam navigation as in the navigation of sailing vessels, in some respects superior; but it will be of that kind which may be, in a greater degree than at present, afforded by landsmen. The skill of engineers, which will be always amply supplied in proportion to its demand, is a new contribution of science to the benefit of the naval service. Military skill will also exert a greater influence in the efficiency of steam vessels than is common in sailing vessels: in the latter, the same men must be necessarily trained to the guns as are at other times employed in working the ship; but in steam vessels, as few seamen will be necessary for the management of their smaller sails, the duties of gunnery may be effectively performed by military men, leaving the great body of our seamen to man our ships of the line and frigates.

It may appear remarkable that steam engines were not earlier applied as a propelling power to vessels, after they had been used as the moving power of other machines. It had long to contend alike with the opposition of the learned and the prejudices of the ignorant: while the importance of a propelling power to supply the action of the wind was generally acknowledged, and was made the subject of a prize memoir by the Royal Academy of Sciences of Paris, Bernoulli, Euler, and Mathon de Lacour, considered steam inapplicable to naval purposes, and recommended the manual exertions of the crew as the best power that could be applied to this purpose. It must, however, be remembered, that at a very early state of the steam engine, it did not possess the capability of being applied with any great advantage to naval purposes; although, after the great improvements which were introduced into the construction of steam engines from 1769 to 1780, this objection to its applicability to naval purposes cannot be considered as the cause of its not being adopted. The almost constant agitation of war, in which every exertion was necessary to maintain powerful fleets, and to render them efficient as sailing and fighting vessels, left but little time to reflect either on the policy or necessary arrangements of so great a change in naval affairs as the introduction of steam vessels would effect. The authority of those scientific men who had condemned the application of steam to naval purposes, the danger which attended its use in working machinery on land, the apprehension of its greater danger at sea, with the exaggerated fear of those unacquainted with its operation and management, and the want of some master-spirit devoted to the object of appropriating this mighty power to naval purposes, together concurred to prevent its earlier adoption. While we claim the invention of steam vessels for our countryman, Mr. Hulls, who published, in 1737, a pamphlet explanatory of his invention, and are indebted to Mr. Symington for further information on the subject, obtained by a series of experiments which he conducted in Scotland in 1802, expressly designed for the improvement of this science, we must assign to Mr. Fulton the honour of applying steam to navigation, with complete success, in America. His knowledge of the subject, and his acquaintance with

the information which had previously been obtained, well qualified him for carrying his views into execution. His first vessel was launched, at New York, in 1807, and fully answered its intended object of navigating the Hudson, between that city and Albany. The application, in America, of steam to the frigate Fulton, was certainly a failure; but an examination of this vessel, leads to the result that it was the failure of an ingenious man, and such a failure as any man is liable to in the early state of any science. To Mr. Henry Bell we are indebted for the successful introduction of steam vessels into use in this country in 1811; since that period their use has rapidly increased, and is still increasing; but so little has yet been attempted in their appropriation to naval warfare, that we may consider that nearly every thing remains to be done in this department of service.

That they will be applied to purposes of naval warfare, in a very extensive manner, their nature and known capabilities lead us confidently to expect. When we contemplate the magnificence of an English fleet of two and three-deckers, we certainly do not wish to see them substituted by a fleet of steam boats. When we reflect on the naval superiority of Great Britain, and are conscious that, with the present system, we must retain that superiority against all opposition, we cannot be pleased, at the first view, of any change by which that superiority can be in any way brought into question. It is not, however, now doubtful whether steam vessels will be invented; their efficiency, as sea boats, has been established by experience: not merely in calms has their advantage been found, but in storms, in which they were at first considered to be extremely dangerous, even if not altogether incapable of sustaining its violence. That they will be used as auxiliaries to ships of the line is admitted by nearly all those, who deny their efficiency as independent ships of war; but there are no arguments which have been brought against the application of steam to ships of war, which are conclusive against their general efficiency. The largest as well as the smallest vessels are equally capable of being impelled by this power; and the reason that ships of the line will probably not be fitted with steam engines, will not be on account of any inefficiency of their

power, or inapplicability of their action, but from the consideration, that the desired effect is expected to be produced more safely and economically by small steam vessels, used as tow-boats, which may also be applied to other services when required. The system of using steam vessels chiefly, if not altogether, as tow-boats, will probably be the first tried, as least opposed to the general feelings of naval men; but the advantage, and, in some cases, the necessity of arming steam boats, will quickly lead to the general adoption of armed steam vessels, the size of which will probably speedily increase from the smaller vessels to frigates.

Whether the invention of steam vessels is advantageous or disadvantageous to the interests of our country, is now become a subject of much anxiety. If steam vessels should universally supersede sailing vessels, if future general engagements should become an action between military steam galleys, we might have some cause to doubt, whether on new principles and with new resources, we might be able to establish the same decided superiority we possess at present, on long tried principles and with sure resources. But we deny the probability that ships of the line will ever be superseded by steam vessels, in general engagements. Large ships are advantageous on the principle, that a greater force can be employed with a smaller surface exposed to an enemy's fire, than in a combination of smaller vessels; and we found our reliance on a continuance of our naval superiority, on the grounds that our superior nautical skill and resources will still exert their effect. The maintenance of this system is certainly the interest of Great Britain; and her energies will doubtless be exerted to counteract any measures which might tend to prevent its continuance. It must be admitted, that as far as steam vessels can be introduced into naval warfare with equal effect to other nations as to England, our relative superiority will be diminished. By considering, however, the different purposes to which they will be applied, we shall find, that in some of the most important, the use of steam vessels will be relatively more advantageous to this country than to others; and by directing the energies of this science principally to these departments of the service, and merely acting in other departments in which steam vessels will

be relatively less advantageous to our interests, as the measures of opposing nations may oblige us to act, we may on the whole be benefited by the adoption of this too much-dreaded invention. For instance, steam vessels accompanying two opposing fleets of ships of the line, as tow-boats, will give the advantage to the attacking fleet, as Captain Ross clearly shows in his valuable work, to which we shall attend in the course of this paper; and this to England, which we have a right to consider as generally seeking the attack in general engagements, in future wars, will be a very decided advantage. In the protection of our coast, and in guarding our commercial navy, armed steam vessels will not only be more economical than the means which we have been hitherto obliged to adopt, but much more effective. In the prospect of a war in which steam vessels will take a prominent place, and on whose efficiency the result of many engagements will depend, we have the satisfaction of knowing that we possess, on the whole, superior resources to any other nation: the excellence of our machinery, the power we have of manufacturing any quantity that may be required, the abundance of coals for fuel, and the numerous ports we possess in almost all parts of the world, will enable us to carry steam navigation to any extent which the exigencies of war may require. On the whole, we consider the prospect of the application of steam navigation to purposes of warfare, to any extent to which it can be carried (and we consider that its limits are restricted within the power of superseding the use of ships of the line), cheering to England, and encouraging that attention to its adoption which circumstances appear now imperiously to demand.

The principal disadvantage attributed to steam vessels, is the danger of their machinery being destroyed by the shot of an enemy; and, although it is probable that danger in this respect will never be totally removed, yet, as its protection will become the particular object of engineers, there is little doubt but that its safety, in this respect, will be sufficiently ensured to render them little, if at all, less efficient on this account than sailing vessels, whose masts and yards must always be exposed to the danger of the shot. With respect to the effect of storms, a steam vessel will be less liable to injury than a sailing vessel,

whose masts and yards have to sustain all their violence. Should the machinery of the steam vessel be destroyed (a case not likely often to occur, with proper arrangements and management), it still possesses its small masts, which afford efficient means of preservation; while the sailing vessel, when once dismasted, has no resource against the fury of the gale. A steam vessel possesses many advantages over a sailing vessel: effecting its course in a calm, or against an adverse wind, is an advantage, which circumstances may render incalculably great; in weathering a storm, and in beating off a lee-shore, the steam vessel has also a decided advantage. As tow-boats generally,—in taking ships of war out of harbour, in bringing ships of the line into desirable stations, in bringing ships from under the fire of a fort when the wind suddenly shifts or dies away, in assisting ships in distress, and taking possession of prizes,—the benefits of steam vessels will be continually experienced. In many instances, the introduction of steam vessels will materially aid the objects of humanity in the preservation of lives, which might otherwise be unnecessarily sacrificed;—at least affording some pleasure in the consideration of an invention which, in many respects, will afford facilities of bringing ships more frequently into action than sailing vessels, without their assistance, could effect. The purposes to which steam vessels may be applied, embrace every service in which sailing vessels are employed, as well as affording some advantages peculiar to themselves. With the exception of their substitution for ships of the line, there is probably no service in which they will not, in another war, be used. There will, no doubt, be numerous failures in their first adaptation to many purposes; but, as there are objects connected with their service which are particularly advantageous to our interests, to these, no doubt, the energies of our country will be especially directed. Experience will be long in this department of science, as in all others, in maturing the construction and equipment of steam vessels, and in adapting them to their intended purpose; and nothing but a war can fully open the wants and difficulties of the subject to our view; and perhaps not till the succeeding peace will the capabilities of steam navigation be fully known, and the necessary improvements be made.

Few works have yet been published on the subject of steam vessels; and although in none of them have its principles and practice been investigated to any great extent, yet considerable advantage may be derived from an examination of them, particularly as affording us very useful information on much that has been done in the practice of steam-vessel construction. M. Marestier's report on the steam navigation of the United States of America is certainly one of the most valuable works yet published on the subject; an analysis of which is given in the third number of this work. Mr. Buchanan's work on steam navigation, published at Glasgow in 1816, is a useful little treatise, containing some valuable scientific remarks on the subject. Mr. Partington's popular description of the steam engine contains a short paper on steam vessels, by Mr. Tredgold, in which he particularly attends to the action of the paddle-wheels. Mr. Tredgold has also given a section on steam vessels in his late very valuable treatise on the steam engine, but certainly much inferior to the other parts of his work. The treatise of Captain Ross, of the Royal Navy, on steam navigation, is deserving of very particular attention, from the comprehensive views and general excellency of its design and execution. The most useful part of his work is that in which the author describes the tactics peculiar to steam vessels, on which his talents and professional knowledge enable him very ably to treat. The tactics of steam vessels are necessarily much more simple than the tactics of sailing vessels, from the facility of altering their course at pleasure, without the difficulties of manœuvres dependent on the force and direction of the wind, and the mean resistance of the water. The order of battle may be always easily formed by steam vessels, either considered as independent ships of war, or as tow-boats to ships of the line. It will not, in a future war, be enough to know the tactics of former years: a new era opens upon us, a new practice of seamanship, and a new system of naval tactics. A work on the tactics of steam vessels now becomes necessary, as an appendix to the invaluable works of Paul Hoste and Mr. Clark. The seamanship of Admiral Penden and Captain Griffiths, with the "naval battles" of Admiral Ekins, will not lose their interest and value, but the information they impart will form but a part

of that knowledge which the naval profession must possess in future wars, in which the combined power of sailing and steam vessels will require expedients and manœuvres hitherto not practised.

Captain Ross insists, throughout his work, on the necessity of the commander of a steam vessel being well acquainted with the principles and management of the steam engine. With the very limited facilities which naval officers at present possess of acquiring an acquaintance with mechanical science, such knowledge is certainly not likely to be obtained very generally. Should naval officers hereafter have the advantage of a more scientific education than their present very early studies afford them, this would no doubt form one of the subjects offered them for consideration.[1]

Captain Ross commences his work with an historical sketch of the steam engine, in which he briefly traces the principal improvements it has received since its invention; in a subsequent chapter, he describes, in a more detailed manner, the late invention of Mr. Gurney's high-pressure engine, which he considers particularly adapted to naval purposes. It can be considered, however, only as an introduction to a more extensive consideration of this subject, which the valuable works of Tredgold and Farey afford us. Mr. Tredgold endeavours, and with considerable success, to explain the principles of steam and steam engines, and has certainly given us the most scientific work hitherto published on the subject. This author has, however, rather too lavishly applied algebraic investigation to all parts of the subject,—not always correctly, and frequently unnecessarily. In his section on steam vessels, he has been much less successful than in the other parts of his work, from the want of a better acquaintance with the principles of naval architecture.

Whether high-pressure or low-pressure engines should be employed in navigation, is become a question of much interest.

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1 The principles and construction of steam engines, with the adaptation of vessels to the different purposes in which steam will be employed as the propelling power, we consider might with great propriety be introduced into the course of studies of the students at the School of Naval Architecture, in Portsmouth dockyard.

Steam engines are generally classed under the heads of non-condensing and condensing engines. Mr. Tredgold gives the following classification of steam engines.[1]

" 1. Non-condensing engines, acting by the	1. Generative power of steam. 2. Generative and expansive power of steam.
" 2. Condensing engines, acting by the	1. Condensation of steam. 2. Condensation and expansion of steam. 3. Generation and condensation of steam. 4. Generation, expansion, and condensation of steam.

" All the engines of the first class, and the third and fourth kinds of the second class, require high-pressure steam. Engines of the first class are remarkable for simplicity of construction, but they never give the whole of the power of the steam. Engines of the second class require a considerable quantity of cold water for condensation, and therefore, in some cases, cannot be applied. The greatest effect is obtained by the second and fourth kinds of the second class; or, rather, it is only in these two species that the whole power of the steam is obtained."

Independently of the peculiar methods of the application of high and low-pressure steam, there is but little difference in their mechanical advantage; as, in raising steam to a higher elastic force, a nearly proportional quantity of heat will be absorbed: so that a certain quantity of fuel would produce nearly equal effects, either by high or low-pressure steam. The most advantageous effect to be obtained by the application of steam, is by high-pressure steam acting by its generative power combined with its expansive power, removing the weights from the piston at different heights, till the elastic force of the steam becomes equal to that of the atmosphere, and then using its remaining power by condensation.

The advantages of high-pressure steam engines on land, in cases where great power is required, are well known; but the

[1] Tredgold on the Steam Engine, page 168.

propriety of their application to naval purposes depends on very different considerations. The advantages which their advocates contend for, in their adoption, are, principally,—greater power, less weight, and less room occupied by them. There is this considerable disadvantage in attempting greatly to increase the velocity of vessels by the application of engines of high power: that the moving force in vessels must be increased as the cube of the required velocity; so that, if a steam vessel be impelled by an engine of fifty-horse power, at the rate of six miles an hour, to obtain a velocity of twelve miles an hour, it would require an engine of four-hundred-horse power. This renders it improbable that engines can ever be applied, of such power as very greatly to increase the velocity of steam vessels. The application of steam to land carriages will not have this difficulty to contend with, as their velocity will be nearly proportional to the power of their engines. The quantity of fuel expended in increasing the velocity of a steam vessel must vary as the square of the required velocity, as the time occupied in moving through a certain distance varies inversely as the power of the engine; so that, in increasing the velocity of the vessel from six to twelve miles an hour, the quantity of fuel must be four times that consumed when the vessel moves with the first velocity.

The advantage to be obtained by high-pressure engines, by the reduction of their weight and the space they occupy, is certainly important in vessels; particularly the diminution of their room, as thereby a greater quantity of fuel can be taken on board. The diminution of their weight will not be equally important in all vessels, as, in some services, heavy steam vessels will be requisite.

One of the benefits of high-pressure engines on land is, that the principle of the expansion-force of steam can be applied much more advantageously to high-pressure, than to low-pressure steam; but this advantage cannot be conveniently obtained in vessels, from the increase of machinery which it would require. In land carriages, high-pressure engines are necessary, from their inability to carry cold water for condensation; but in vessels, the surrounding water affords a ready supply for this purpose.

But the great objection to high-pressure engines, is their greater danger of explosion. In low-pressure engines, the steam acts with a force of from two and a half to four pounds on a square inch of the boiler; while, in high-pressure engines, which have to act against the pressure of the atmosphere, the force is generally from 40 to 50 pounds on a square inch, and frequently much more. The constant action of this enormous force on materials gradually becoming weaker, and the deficiency of the strength of which is frequently not discovered till evinced by its consequences, are serious objections to its use, whatever confidence we may have in the knowledge of the engineer, who adapted the strength of the parts of the engine to the strain which they have to sustain, and in the attention of those to whose care it is intrusted. Too much reliance is frequently placed on the safety-valve, strict attention to which, is considered by many as all that is necessary to prevent the explosion of the boilers; there are, however, cases in which no attention to the safety-valves can prevent it,—indeed, in some instances, the opening of the safety-valve may occasion it. The other expedients for allowing the steam, when raised to an excessive power, to escape, by having parts fitted to the boiler, which should give way to a certain high pressure, or should fuse at a certain increased temperature, are also in some cases equally unavailing. Instances have occurred in which explosions have taken place, when immediately before, the engine has worked slowly, and the height of the column of mercury in the gage has been less than usual. When the force of the steam *gradually* increases by the action of the heat, it is generally indicated by the rising of the column of mercury, and in those cases, the safety-valve strictly attended to, and the other expedients, will ensure the safety of the boiler. But when the steam is suddenly raised to a very high power, these means of safety are frequently unavailing.

M. Marestier has lately published some remarks "on the explosions of steam engines, and on precautions to be taken to prevent them," in the *Annales Maritimes et Coloniales.* His theory of the explosion of boilers of steam engines, differs in some respects from that of Mr. Perkins on the same subject, given in his late papers. M. Marestier, in this ingenious

paper, observes, "the[1] most important remark which is suggested by the examination of the circumstances which have accompanied the fatal explosions which we are considering, is that, almost always, there are signs that there was a deficiency of water in the boiler. If we admit that the water, by an insufficient supply of the boilers, has left a part of the sides exposed to the fire uncovered, this part no longer serving for the formation of the steam, the column of mercury will be seen very soon to fall; and it will become necessary to increase the strength of the fire, in order to draw from the other parts of the boiler all the steam which is required. The uncovered surface will acquire a high temperature, and will even become of a red heat; it will transmit a part of its caloric to the exterior sides, as well as to the steam, and will, perhaps, decompose a portion of the steam in contact, in absorbing the oxygen which it contains, as happens when the hydrogen of the water is extracted in a cannon raised to a red heat. When this is the case, traces of oxidation will be found on the metal, which have sometimes been remarked after the explosion. The temperature of the metal while it is covered with water, is little more than that of the water, at least if the metal is not very thick. Immediately it receives caloric, it communicates it to the water; and if the water is already hot, it forms bubbles of steam, which increase the excess of the caloric; so that if the fire did not furnish a fresh supply of it, the metal would be instantly brought to the temperature of the water. When the water does not cover entirely the stoves and the passages of the flame, the caloric accumulates in the portion of the metal which is in contact only with the steam; and if, by any cause, such, for instance, as the inclination of the steam vessel, the water spreads suddenly over the red-hot parts, it seizes on the superabundant caloric, and the instantaneous production of a certain quantity of steam is the result."

M. Marestier proceeds to determine the quantity of steam which may be produced by the sudden contact of a certain quantity of red-hot iron and water. He determines, that in an engine of a hundred-horse power, as much steam as the boiler contains may be suddenly produced by the contact of the water

[1] Annales Maritimes et Coloniales, for 1828, page 1000, et seq.

with a square metre of the surface of the boiler, raised to a red heat, so that the force of the steam would thereby be nearly doubled. By the contact of the water with two, three, &c., square metres of red-hot surface, the force of the steam is rendered triple, quadruple, &c., the force it had previously. As the surface of the boiler of an engine of a hundred-horse power presents about a hundred square metres of surface exposed to the action of the fire, it may be easily conceived, he observes, that many square metres of surface may become red-hot; and, consequently, that a violent explosion may destroy it, if it is neglected to keep the water in the boiler at a proper height.

He continues, "I have indicated the movements of the steam vessel as one cause, which may bring the water on the parts of the boilers rendered red-hot by the action of the fire; but I do not believe it the most common, and it will not explain the explosions which take place in establishments on land. Let us conceive that, in a boiler, the temperature of the water is at 105 degrees, the force of the steam above the pressure of the atmosphere will be, measured by a column of mercury, about fourteen centimetres high: if the steam can issue freely through the safety-valve, or through any other opening, this force will tend to reduce itself to the atmospheric pressure, as the steam disengages itself, and to descend to 100 degrees.

"Let us suppose, for instance, that the boiler contains 28,000 kilogrammes of water, which is the capacity of the boilers of a certain form, for an engine of a hundred-horse power; these 28,000 kilogrammes of water, in passing from the temperature of 105 degrees to that of 100, will lose, each of them, five degrees, and consequently, together, as much caloric as is necessary to raise 140,000 kilogrammes of water one degree of temperature; but, as we have already remarked,[1] that it requires the quantity of caloric which would raise 560 kilogrammes of water one degree, to make a kilogramme of water pass into steam; that which would raise 140,000 kilogrammes of water one degree, would make 250 kilogrammes of water pass into steam (since 250 multiplied by 360 give 140,000); and as each kilogramme of water furnishes 1700

[1] At page 1002, Ann. Mar.

litres of steam, we may conclude, that the water of the boilers will be reduced to 100 degrees only after it shall have disengaged a quantity of steam equivalent to 425,000 litres, or to 425 cubical metres of steam, at the degree of tension of the atmosphere."

"This remark shows why steam takes much time in disengaging itself, when the safety-valve is opened. Immediately the disengagement commences, the pressure of the steam on the surface of the water diminishing, it is no longer only from the sides exposed to the fire that the bubbles rise; bubbles are formed everywhere, which augment the volume of the water, and raise its level.[1] There is also another cause, the effect of which is particularly sensible in the boilers with plane sides: these sides, pressed less internally by the steam, in proportion as it loses its force, straighten by the effect of their elasticity, diminish the volume of the boiler, and contribute to raise the level of the water.[2]

"From these considerations, if they are well founded, it appears clearly to result, that at the moment when the safety-valve is opened, a great effervescence must manifest itself in the boilers; that, as well from this cause as from the effect of the straightening of the sides, the level of the water must rise; and that, if any part of the boilers exposed to the fire, having been left uncovered by an insufficient supply of water, has acquired an elevated temperature, the water, in rising over this part, will experience an extraordinary ebullition, and will de-

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1 "The water is then in the state of a liquid containing gas in solution, such as effervescent beer or wine: as soon as the cork is drawn from the vessel which contains it, an infinite number of bubbles show themselves in the liquid, and increase its bulk so as often to make a great part flow from the vessel.

2 "After the boilers have been some time in use, they get out of shape, and the surfaces which were at first plane, become commonly convex externally. When the atmospheric pressure exceeds the force of the steam, the faces not only straighten, but even become suddenly concave. This change, which almost always takes place with a noise, because all the parts of the boiler vibrate, occasions a remarkable elevation of the water; but sometimes this elevation is not perceived in opening the cocks intended to mark the level, because the air enters, and neither water nor steam escapes; we can then only judge that the level is above the cocks, by the noise the air makes in passing through the water.

velope simultaneously a great quantity of steam, which may cause the most terrible explosion.[1]

"The first consequence of this conclusion is, *that the greatest care must be taken to keep the water in the boilers above the surfaces exposed to the action of the fire;* the second is, that if, by negligence or any other cause, the water is lowered, and has left a part of the stoves, or of the passages of the flame uncovered, *the safety-valves and fusible parts would become dangerous precautions:* it would be imprudent to give to the steam an issue of any extent; we would advise that the fire be not fed, that the doors of the stoves be opened to render the fire less active, and if it can be done, that a part of the water of the boilers be drawn off, in order to introduce cold water, but without allowing the level to rise to the parts of the boilers which have been uncovered; that the engine should continue to work, but that the expenditure of the steam be regulated by means of the register which is on the tube of communication between the boilers and the cylinder, so that the elasticity of the steam diminish slowly; and if, when the register is quite open, the elasticity should continue to increase, that sand or cinders be thrown on the burning coals, or even that the coals should be gradually withdrawn.[2]

"When the temperature is reduced to 100 degrees, and the manometer indicates that the steam has no longer any force, the safety-valve may be opened without inconvenience, and the use of the hand-pump may be continued to finish filling the boilers. The water only rising slowly, the steam will probably not be formed sufficiently rapid to produce an explosion: however, if these parts should present horizontal surfaces too great, and the steam should be observed to be disengaged too abund-

1 "In order to render the boilers of steam vessels light, less water is admitted over the stoves than in the boilers on land; the passages of the flame are closer and more numerous; the water is also sooner carried off, and the steam disengages itself with more difficulty. These are the reasons that the explosions are more frequent in vessels than on land. As the supply of the water lessens the motion, it happens that it is suspended too long when two boats are in competition.

2 "As every sudden change is to be feared, water should not be thrown either into the stoves or on the fire. We do not think it would be right to stop the machine, unless the force of the steam diminishes too rapidly.

antly by the safety valve, it would be necessary to relax in working the hand-pump, or to stop it till the boilers are cool; the fire should not be rekindled, till the water has entirely covered the stoves and the passages of the flame."

Mr. Perkins considers the excess of the caloric in the steam, as one of the principal causes of the sudden production of steam, which frequently causes the explosions of the boilers; M. Marestier, while he admits its action, considers that it is by no means the principal cause, attributing this effect chiefly to the contact of the water with the heated metal. They agree in the danger occasioned by the safety-valves opening in case of the sudden formation of steam; their principal difference in practice, consists in Mr. Perkins considering that the machine should be stopped, while M. Marestier recommends that it should continue to work. In other respects their practice would be nearly the same. The most important precaution against this danger, agreeable to the reasoning of both, is to keep the boilers sufficiently supplied with water, that parts of them may not become red-hot, which is the cause of the sudden formation of the steam which produces the explosion.

A consideration of the causes of these explosions shows that very considerable professional knowledge, as well as the greatest possible attention, are necessary in taking charge of steam engines; and that there are additional dangers to be guarded against in engines on board vessels. In high-pressure engines the danger is unquestionably greater than in low-pressure engines, from the great strength of the steam, the increased rapidity of the engines' wear, and from the strong heat which is necessarily kept up; which not only destroys the boilers faster than with low-pressure engines, but, in cases where the water does not cover all the parts exposed to its action, rapidly renders them red-hot, and increases the danger of their explosion. At the same time it must be remembered, that low-pressure engines are liable to the explosions caused by the sudden formation of steam; and although the causes which ordinarily produce them are not in equal action in low-pressure as in high-pressure engines, yet that there are dangers in these engines also, which require the greatest attention of those who have the direction and charge of them. Low-pressure engines

admit of a peculiar means of ascertaining the state of the boiler, by means of tubes, which have their lower ends immersed in the water in the boiler, and their upper ends formed of a trumpet shape, which emit sounds indicative of the ebullition of the water; a precaution which might generally prevent explosion, in low-pressure engines.

There may be, and most likely will be, cases, in which particular services of steam vessels will require every possible advantage of power; and in such cases high-pressure steam will be necessary, and may be successfully employed. The adaptation of these engines to naval purposes is well worthy attention; and there is no doubt that engineers will succeed in inventing precautionary means of reducing their danger. The tubular boilers of Mr. Gurney have some peculiar advantages, particularly in diminished danger and in the capability of quickly raising the steam. When this kind of boiler shall have been further improved, it will probably be found to be well adapted for those naval purposes, in which high-pressure engines may be required.

While high-pressure engines do not offer any great advantages in ordinary service, we consider that their greater danger appears a sufficient reason against their general use.

The proportions and forms of steam vessels have hitherto been but little investigated: while the engines which are to propel the vessels have been continually receiving numerous advantages from scientific inquiry and practical knowledge, the construction of the vessels themselves has not been much improved. If steam vessels were to be constructed entirely with reference to the moving force of the steam engine, their design would admit of a much nearer approximation to perfection, according to the particular service of the vessel, than at present can be expected to be attained in the design of sailing vessels, whose moving force presents numerous difficulties in the mutual dependence on each other of the form of the vessel and the masts and sails. Little has yet been done even in this respect; but the adaptation of vessels to act efficiently as sailing vessels as well as steam vessels, has been yet more neglected. In many services steam will be only an auxiliary moving power; and the qualities of a good sea-boat must not be sacrificed to

the velocity of the vessel, which is the chief consideration in the construction of a vessel merely used as a steam vessel. In steam vessels intended for independent service at sea, their stability should be particularly attended to; and, to possess this quality in a proper degree, their breadth will require a great increase.

Captain Ross divides steam vessels intended for war into four classes: "first, those intended for cruising; secondly, auxiliaries to ships of the line and frigates; thirdly, for protection to the coast; and fourthly, for despatches and convoys." He gives some general remarks on the form and fitting of these vessels according to their particular service: he observes, that "the first class should be made to combine the qualities of a sailing vessel with those of a steam vessel; but as sailing must in all steam vessels be considered the secondary quality, the construction, or the proportions of a ship of this nature, must partake more of the form necessary to a vessel moved by this machinery, than to one dependent only on her sails. The length and breadth ought to be greater in proportion to the depth; and a vessel of this nature must be also flatter in the floor than is usual in sailing vessels." He gives the dimensions of a steam vessel, called "The Town of Drogheda," which, he says, "is known to have possessed the best qualities, both under the action of the engine, and that of the sails," which plied in the Irish Channel. The sponcing of this vessel was formed by carrying up the timbers of the frame, curved outwards, to enclose the paddles above the water: a plan which he recommends for security and strength; but which, as it requires timber of considerable curvature, and affords no greater strength than could be obtained by carrying up the timbers of the frame and having an independent framing, appears to offer no particular advantage. Her length of keel was 116 ft.; length on deck 130 ft.; breadth between the paddles 23 ft.; extreme breadth $27\frac{1}{2}$ ft.; depth of the hold 13 ft.; and draught of water, with engines and coal, but without cargo, $9\frac{1}{2}$ ft. The author observes, "the proportions of this vessel may be increased to the size of the largest ship in the navy; in which case it will be necessary only to add to the number, instead of the size of the engines. The stem and forefoot of a steam ship of this

kind should be narrow, and with about an inch in the foot more rake than in sailing vessels; but the keel ought to be equally deep: the object of the first being to give the rudder more command; and of the second, to prevent rolling and falling to leeward when cruising under sail. The bow, above water, ought to be full; forming, with the stem, nearly a horizontal semicircle, and with the forefoot, a vertical one; which proportions have been found best both for safety and velocity. The floor ought to be flat, both for the sake of buoyancy and convenience; because a vessel of this construction will displace less[1] water, or at least, the water which she displaces, will be nearer the surface, whence she will require less force to impel her through it. The run ought to be very clean, and she ought to draw rather most water abaft. The rudder should, in its proportions, be one-fourth, or according to the length and size of the vessel, one-half broader than in sailing vessels; the direction of the vessel being, while under the power of steam, often entirely dependent on the helm; the sternpost and rudder also both ought to be secured in the strongest possible manner."

With respect to the second class of steam vessels, those intended as auxiliaries to ships of the line and frigates, Captain Ross observes, that "as such a vessel can always be taken in tow, under other circumstances, her masts or sailing qualities, are of much less importance than in the case of a cruizer. The weight and solidity of a vessel of this kind will always be an advantage, inasmuch as it will add to the momentum; or, when once set in motion, the *vis inertiæ* will be more able to overcome the inequalities of resistance, occasioned by the sea acting on both ships. Vessels constructed for these services should therefore be made as strong as wood and iron can make them; indeed, they may be so far fortified as to resist shot at any distances where it would take complete effect in the sides of her consort; at any rate, the part which contains the machinery should be fortified in that manner. The dimensions of this kind

[1] This remark we consider accidental, as the author, no doubt, is fully aware, that, whatever be the form of a vessel, it displaces a quantity of water equal to its weight.

of ship should be nearly those of the vessel already mentioned, except that she should have two feet more depth of hold, to enable her boilers, and other parts of the machinery, to be placed under the water-line; which, with the exception of the shaft and crank, may be easily done. There are inventions indeed which, if they succeed, will remedy that defect also, and thereby render the auxiliary steam vessel, not only perfectly secure from injury during a general action, but fully able both to assist in keeping her consort in her station and in annoying her opponent. A more minute detail of the construction of this kind of ship must be withheld for obvious reasons. As to the masts and rigging, being objects so comparatively small, it is only requisite to say that they should be constructed so as to lower entirely down, when the vessel is wanted for service. The engines will of course be powerful in proportion to the size of the vessel, which will be dependent on her consort for fuel, and she will either be always towing, or in tow of her consort."

The third class of steam vessels, those designed for the defence of the coast, Captain Ross describes as not differing in the construction of the hull from cruising vessels; the only difference requisite being in the masts, sails, and rigging. He observes, that "as the quantity of fuel is of less importance, the engines may be made more powerful, and secured from the effects of shot at a distance of six hundred yards." Sketches are given of the method of protecting the vessels by a convex covering, "the details of which," the author says, he "withholds for obvious reasons." The sketches convey no definite notion of the manner in which it is to be carried into practice, and might have been omitted without diminution of information.

The fourth class of steam vessels, those to be employed in the protection of the trade and convoys, Captain Ross observes, "should combine the qualities of a sailing vessel and those of a steam vessel; and, indeed, would differ very little in the appearance of the hull from a sloop of war. These vessels will sail faster under sail only, than most of the convoy of common merchant ships; and if they accompany a convoy of Indiamen, they can be kept in tow by one of the fastest sailing ships, while she will be at hand to tow the Indiamen in her turn, when calm,

or in light winds. The engines should be more powerful, on purpose to tow up those ships which get astern and to leeward; and as they will look to the ships of the convoy to replenish the fuel when required, they will be able to afford more room for the machinery." He considers the proportions of the steam vessel before-mentioned, the Town of Drogheda, as well suited to this class of vessels.

Captain Ross makes some observations on the masting and rigging of steam vessels; but uniformly insists on the secondary importance of every thing connected with the sailing of these vessels. He considers that all steam vessels intended for sea service, not above the size of a frigate, should have three masts; and those above that size, four masts. Schooners' masts are recommended as the guide in determining the proportions of the masts of steam vessels: reducing the lengths of the lower masts about one-third of those of the sailing vessels. The topmasts are recommended to be light, and to be always struck before a gale, and when propelling against the wind: that there should be no top-gallant-masts; and that cross-trees should be used instead of tops. The fore-mast and mizen-mast are recommended to be placed close to the extremities, to assist the steerage. It is also observed, that the yards should be small in proportion to those of a schooner; and that the sails "should consist of a fore-and-aft sail to each mast; these being intended for the usual wants of the vessel, while there should also be a trysail to each mast, to be set in storms. If rigged with three masts, she should have two topsails; if with four masts, three; no topsail on the mizen-mast being necessary in any case. She should also have two storm-staysails fitted to the short topsail-yards, and made of stout canvass; the use of these being for the purpose of scudding, and for *lying-to* in a storm, when the sea is heavy. A square-sail should be fitted for the fore and main yards; but that should always be set flying; or, in other words, from the deck. Lower and top-mast studdingsails may be also used at times with advantage; and there should also be a staysail to each mast, together with a jib and flying jib, as in a sailing ship."

The rigging required for steam vessels is necessarily much less than for sailing vessels; and may, by attention, be made to

hold but little wind. Captain Ross recommends a decrease in the number of the shrouds rather than in their size; and that the topmast rigging may be lowered on deck with the topmasts, and the braces sent down with the yards, &c. He observes, that the bowsprit should "be well secured, as, in propelling against the action of the waves, it will frequently be severely tried: the bobstays should be double, and also considerably stronger than those required for a sailing vessel of equal tonnage; the bowsprit should also be double-gammoned, and on the upper side, well supported by an oak fish. The jib-boom should also be strongly rigged, with double guys leading to the forecastle, and fitted so as to be quickly and easily sent on deck."

Throughout all these remarks, the sailing qualities of the vessels are not considered of that importance of which we conceive they will be found in general practice. The relative dimensions of the steam vessel, the Town of Drogheda, which are recommended for adoption in their design, will afford but little stability, and in case of their being, by accident to the engine, compelled to depend wholly on their sailing qualities, the vessels would not be able to carry a sufficient quantity of sail to beat to windward, which, in the instance of being embayed on a lee-shore, would probably be fatal. The variation in the relative dimensions and form required for different services are not sufficiently defined. It may be observed also that the recommendation to construct steam vessels of all sizes similar to this vessel, would give very different qualities to large and small vessels, although it is to be supposed that it was intended for them all to possess equal qualities. Why the bow, above the water, should form, "with the stem, nearly a horizontal semicircle, and with the forefoot a vertical one," to give safety and velocity, no reasons are adduced; except the assertion that these "proportions have been found best both for safety and velocity." The essential properties of a steam vessel depend on many other elements of the design; and certainly in a greater degree than on these particular forms, even supposing that reason had been shown for their adoption: such as the proportion between the length, breadth, and depth, the total displacement, the area and form of the midship section, the relative fulness of

the fore and after bodies, the form of the body, and the quantity and disposition of the weights. The flatness of the floor recommended is detrimental to a fine run to the rudder, and to lateral resistance, both very important considerations in the construction of all vessels. That a vessel with a flat floor, with a given displacement, will displace the water nearer the surface than a vessel with a rising floor, is true only when the breadth is not to be increased in the vessel with the rising floor; but even in those steam vessels which do displace the water nearer the surface than others, there will be very little difference in the direct resistance, as the total draught of water of these vessels is always small. This principle, in the resistance of fluids, is frequently much over-rated, particularly in steam vessels, as it requires a depth of about thirty-three feet below the surface to double the pressure of the water on a given surface: in ships which draw from twenty to twenty-five and twenty-six feet of water, this principle may be with more propriety considered in estimating the resistance they experience in moving in the water.

The construction of steam vessels offers a very extensive field for the range of theoretical and practical investigation. The subject requires an attentive consideration in detail under the following heads: the size of steam-vessels according to their particular services; their relative dimensions, form, and stowage, on which depend their capacity, stability, velocity, rolling, pitching, steering, and masting; the kind of engine best adapted to naval purposes, the situation, number, and form of the paddles, and the fuel for the engine; the practical construction of the vessels for strength, and for protection from shot; and the best means of arming them. The practical consideration which these parts of the subject have already received, we trust will speedily be followed by more extensive investigations, by which sure and practical results may be obtained. Mr. Tredgold's division of the subject in his tenth section of his treatise on steam-navigation, is the most comprehensive yet attempted, but his investigations are very inadequate to his design; should he resume the subject, we may hope it will receive more advantage from his labours.

The determination of the size of steam vessels for different

services and particular stations, will demand much consideration, and great knowledge of the harbours and coasts they will be required to navigate. Though a superiority of number rather than of size will be advantageous in engagements between fleets of steam vessels, yet the size of steam vessels will, in some cases, be of equal importance to the size of sailing vessels; as their weight will greatly increase their momentum when they attack an enemy by the impact of their prows, and will also be particularly advantageous in towing other vessels. The relative dimensions of steam vessels have generally been determined arbitrarily, with little reference to the elements of the design their variation affects.

Mr. Buchanan in his treatise on steam boats, makes some observations on the stability of vessels, which evince but little knowledge of the subject. He remarks, that experiments on different bodies would produce results by means of which the comparative stability of various forms may be estimated; and gives the results of experiments made by Mr. Gore, who undertook to arrive at conclusions on a subject by experiment, which is capable of correct measurement, from the lineal dimensions and form of any vessel, and from the determination of its centre of gravity. Necessary as experiments are in the investigation of many of the laws of fluids, particularly in the resistance which bodies experience in moving through them, they are worse than useless in those departments of science which depend on well-known mechanical laws, which can be with certainty applied to practice; as the best models are liable to incorrect adjustment, and, in most instances, can only determine the results with accuracy in the simplest cases. We do not want to be informed by experiment of the force which will incline bodies of various forms to different angles from the upright position: we can with accuracy and certainty determine this by lineal measurement and calculation; and if the results of experiments on this subject should not agree with our conclusions, we are quite sure that the disagreement arises from errors in the experiments. If the knowledge of the principles of naval architecture were generally better understood, much trouble and expense might be saved, in making experiments, which very imperfectly show results, which are already

well known to those acquainted with mechanical science. Mr. Tredgold's investigation of this subject, though very differently conducted, will be found not more useful in practice. He distinguishes the stability of vessels by its being longitudinal or lateral: on the longitudinal stability, he observes "a vessel at rest would be least disturbed by the motion of the sea, if its surfaces at the water-line were vertical ones; and the fore and after parts of the same figure; but in motion it is an advantage that the parts should spread above water, both fore and after, to prevent the vessel burying its head in the wave, or dropping behind as the wave leaves it. The quantity of motion is not increased by this construction, provided the parts produce similar effects, and the degree of inclination should be proportioned to the velocity the vessel is expected to make. It is also obvious that the vessel will be more easy in its longitudinal motions, the more gradually it terminates at its extremities. If the vessel be inclined by the action of a lateral force, the longitudinal motions will be more easy in proportion as the cross section approaches to that of a solid of revolution. On the lateral stability, he observes "the inequality of the surface of the sea will alone produce considerable lateral motion, if the sides be not sensibly vertical, hence, in sea-vessels, lateral stability should not be obtained by form at the surface of the water. The next important consideration is that the stability should be equal throughout the length." In these remarks there is a great want of perspicuity as to the rolling caused by the action of the waves, and the stability, or force by which a vessel, when inclined, is restored to its upright position. It is also implied in these observations, that vertical sides do not give the greatest stability as to form; whereas with a given length and breadth, it has been proved, that the stability in two vessels, *cæteris paribus*, is the same, the sides of the one of which are vertical planes, and of the other, arcs of parabolas of any order, falling out above and falling in below the water line; and that the stability of both these vessels is greater than that of a vessel whose sides are planes inclined outwards above the water. These observations are

1. See Atwood's paper on the stability of Ships in the Ph. Trans. of the Royal Society, for 1798.

correct only as far as they show, that the momentum of the strokes of the waves is greater in ships which project outwards above the water than in those with upright sides, which is in consequence of the direction of the stroke passing at a greater perpendicular distance from the axis of revolution. As to the stability being 'equal throughout the length,' no such condition is necessary, either for equalizing the strain of the vessel, or for regulating the motion: the inclination caused by the momentum of the waves can be overcome only by the stability of the whole length of the vessel; and the regularity and ease of the vessel's motion in inclining are produced alone by the momentum of stability increasing gradually; and by the centres of gravity of the parts immersed and emerged by the inclination, continuing always in the same transverse plane, by which diagonal inclination is prevented. Mr. Tredgold's mathematical investigation of the stability of vessels whose transverse sections are parabolas of different orders, is erroneous, from his considering the parts immersed and emerged by the inclination as triangular instead of parabolic areas. The stability of steam vessels, which are intended for sea-service, should be always correctly determined, not merely in respect to the inclining force of the waves, but also in relation to the inclination caused by the sails. The relative breadth of vessels is the principal element of this quality, and it is chiefly to the determination of this dimension the first consideration should be given; the form within the limits of the immersion and emersion may then be considered. The position of the centre of gravity of the steam vessels should also be correctly ascertained. We consider that the stability of steam vessels will require to be considerably increased, which must be done by increasing their relative breadth, in order to render them safe and efficient vessels in the extensive services in which we expect they will be employed.

Although the velocity of steam vessels has received more attention than their other qualities, very little practical benefit has yet resulted from it. Steam vessels, however, are likely to receive earlier advantages from the results of experiments on the resistance of fluids, than other vessels, from the nearer agreement of the motion of the models used in the experi-

ments with the motion of steam vessels, than with the motion of sailing vessels. Mr. Buchanan explains the nature of the subject as elucidated by Sir Isaac Newton, M. Buat, Dr. Robison, and others; and gives the results of the best experiments made on this subject. His remarks are rather of a general character, than directed to a particular application to the forms of steam vessels. Mr. Tredgold's theory of the resistance of fluids is neither marked by any elucidation of their action, nor by any excellency of mathematical investigation; he has, however, by neglecting the most difficult parts of the subject, obtained a rule for calculating the resistance which steam vessels experience in their motion, which appears to agree tolerably well with the experiments made by Mr. Bevan on canal-boats. The late experiments made by Mr. Walker with boats in the last India Import Docks, the results of which are published in the first part of the Philosophical Transactions of the Royal Society for 1828, are amongst the most useful attempts recently made for the improvement of our knowledge of the resistance of fluids. His ingenious method of obtaining the resistance, without including the friction of the machinery of the moving force, or the friction of the connecting line in the water, renders his results worthy of particular attention. "A spring weighing machine was fixed near the bow of the boat, the dial laid horizontally, so as to be easily seen by a person on board; one end of a line three-eighths of an inch in diameter, was attached to the hook of the spring, the other end was carried ashore and attached to a reel or barrel three feet in diameter, the frame of which was firmly fixed in the ground, and the handles of sufficient length for the necessary number of men to turn the barrel. The velocities were calculated from the time of passing through 176 yards, or one tenth of a mile; but to obtain uniform velocity, the boat was at each experiment drawn over twice the length, and the 176 yards taken in the middle of the distance by two marks on the line. The time between the two marks coming to the edge of the dock, was carefully noted by a person stationed there for the purpose. Three persons at least were on board the boat; the one to read off the strain shown upon the dial every two seconds, one to write them down, and a

third to steady the boat.—The index of the dial on board the boat measured the resistances to the boat only. The experiments in the following table were made in a full-built boat loaded with two tons, two cwt., exclusive of the men. The length of the boat upon the surface of the water was eighteen feet, six inches; the breadth six feet; the depth of immersion two feet; the whole depth of the boat being three feet, leaving one foot above water, and the greatest immersed cross section nine feet.

Number of experiments.	Seconds in passing 176 yards.	Miles and decimals per hour.	Actual resistance in pounds.	Calculated resistance in pounds, taking No. 5 as standard.
1	124	2.903	15.75	15.04
2	85	4.235	39.50	32.01
3	146	2.465	10.00	10.85
4	140	2.571	11.00	11.80
5	145	2.483	11.00	11.00 standard.
6	140	2.571	12.00	11.80
7	120	3.000	14.00	16.06
8	120	3.000	14.00	16.06

"In almost every experiment, the resistance shows an increase amounting to the square of the velocity; but where the velocity is considerable, the resistance follows a still higher ratio, and this in open water. In narrow canals the increase must be considerably greater."

The experiments hitherto made by this gentleman, are interesting, rather from the manner in which the results were obtained, than from any excellency in the design of the experiments, as calculated to afford information on any part of the subject not already attempted. As, however, he informs us, that he intends to prosecute the subject, we may look forward with interest to a more extensive series of experiments, and we hope by especial attention to some particular objects, that the subject will obtain some practical benefit from his labours. The disagreement he found between his own results and those

of the French Academy, and those by M. Bossut in the absolute resistance, may probably be accounted for by an attention to the resistance arising from the different forms of the after-parts of the bodies used in the experiments.

In calculating the resistance a steam vessel experiences, the resistance of the paddle-wheels in the direction of the vessel's motion should be added to that of the vessel, estimating the resistance of the paddles by the relation of their velocity to that of the vessel. This is neglected in the calculations of the resistance of steam vessels by authors on the subject. The same result might be obtained by subtracting it from the resistance of the paddles in the contrary direction to that of the vessel. As the size of the paddle-boards, in relation to the whole plane of estimated resistance, is influenced by this consideration, it certainly merits attention.

The paddles of steam engines have engaged the attention of engineers and others, as much as any part of a steam vessel, and considerable knowledge has been obtained on the subject. Their situation as to the length of the vessel, however, has not yet been strictly determined: the principles which, in sailing vessels determine the situation of the centre of the sails, do not determine the situation of the paddles. Some steam vessels used on rivers have their paddles abaft the vessel, by which they are protected from collision with other vessels; but in a sea this disposition would be disadvantageous, from the paddles being alternately immersed by the vessel's 'scending, and raised out of the water by pitching. In some vessels the paddles have been placed in the middle, transversely, by which they are undoubtedly well protected, but their effect in propelling the vessel is much diminished by the current and eddy water. This is the chief defect in the American steam frigate, which was found to move very slowly. The most convenient situation of the engine, for general service, appears to be near the middle of the length, where it can be best placed for stowage, for the disposition of its weight, and for support in the full part of the body; in this situation it also admits of being well protected. The effect of the paddles on the water is greater before the middle than abaft, from there being a current running towards the stern, abaft the greatest transverse

section, caused by the rising of the water forward; so that the best situation of the paddles, is probably a little before the middle of the length.

Mr. Tredgold's investigations and remarks on paddle-wheels, are valuable and interesting. The form of the paddle-boards which he recommends, decreasing in breadth downwards, is advantageous, as "by this form, the resistance to the paddle is least when it strikes the water obliquely, and increases as its action becomes more direct." He recommends the form of the paddle-boards to be parabolic, although he does not show this to be the curve of the maximum effect; the principle, however, is given, and the only objections are, the difficulty of the security of the paddle-boards of this construction, and the greater breadth of paddle which is required; the increase of breadth would not, however, be so great, as to be any great practical objection. Substituting depth for breadth in paddle-boards, preserving the same area, has been recommended for diminishing the exposure of the paddle-wheels and boxes to accident; but the effect of the paddles is thereby greatly diminished, and cannot, therefore, be adopted advantageously much beyond their present limits. The number of the paddles is restricted by the necessity of there being "time for the water to flow between them, so as to afford a proper quantity of re-action," and that they may "clear themselves well in quitting the water." Experience shows that the number should not be much greater, than to allow, as one leaves the water, the succeeding one to be vertical. To reduce the uneasy, tremulous motion in steam vessels, the paddles have in some, been placed obliquely; and, in others, narrow transverse paddles have been arranged so as to form a spiral round the wheel: both these methods reduce the power, although they succeed in rendering the motion more equable.

The tactics peculiar to steam vessels, are not less important than their construction; and it is gratifying to perceive, that this part of the subject has received, by the valuable labours of Captain Ross, at least as great benefit by the illustrations and directions given in his work, as any other part of the subject has yet received: the whole of his remarks are deserving of the

greatest attention. He commences this part of his work, by a consideration of the anchors most appropriate for a steam vessel, which, he observes, "may be considerably less in weight, than those required for a sailing vessel; first, because her masts, rigging, and upper works afford less hold to the wind, because her length renders her a better roadster, and because she draws less water." He recommends chain cables, which may be used in trimming the ship; and that the messenger may be connected with the shaft of the engine, by which it may be easily hove up. He observes, that in a calm, a ship should have steam-way by means of the engine, before the anchor is let go, and that from five to ten fathoms, according to the depth of the water, should be veered to cant the anchor, by which a chain-cable will never get foul. In anchoring in a tides-way, the ship's head should always be brought to stem the tide, whatever the direction of the wind may be; and the ship should go a-stern before the anchor is dropped. In riding at anchor in a storm, the engine may be used with great advantage, in easing the strain on the cable, by which the ship will ride more easily, and by which the cable and anchor will be greatly assisted. Steam vessels, by these means, often ride out a storm, when sailing vessels are driven from their anchors; and should the cable part, the engine may often save the vessel.

Captain Ross makes some excellent remarks on the use of sails in steam vessels; but, we think, without estimating their advantage so highly as their use would justify. In light breezes, he observes, that even with the wind four points before the beam, there will be an advantage in setting the fore and aft sails, as these sails, when there is a little swell, will keep the ship steady, and allow the engine to act more regularly. He observes, however, that the sails should not be used when the direction or strength of the wind is variable, as more will be lost in trimming, and thus deviating from the course, than would be compensated by any trifling advantage. When there is a light breeze abaft the beam, he recommends, that sails should not be used if they would not propel the vessel with a velocity of at least five knots an hour, unless a try-sail be used to prevent rolling. When there is a light breeze

right aft, he recommends the sails not to be used, unless the velocity afforded by the sails alone, would exceed that produced by the engine.

The advantage of the steam engine is particularly felt in a gale, which many at first feared would be more dangerous to a steam vessel than to a sailing vessel; indeed, it was by some considered, that gales would be fatal to steam vessels; whereas experience has fully established, that they can often weather storms which prove fatal to sailing vessels. Captain Ross observes, that a steam vessel has exactly the masts, rigging, and sails, which would be most advantageous to a sailing vessel in a storm; and better than they really can possess, being able to show more canvass, and consequently to keep her head-way better; that she will be more weatherly, and not be so apt to fall off, and that drawing less water, she will be more lively: all these advantages she possesses under canvass only; but when the effect of the engine is added to these advantages, the author observes, the question of safety is beyond a doubt. We consider, however, that a deficiency in stability with the usual proportions of steam vessels, must be seriously felt in a gale, when the vessel is dependent only on her sails.

Captain Ross remarks, that it is fully established by experience, as well as by theoretic reasoning, that the best way for a steam vessel to make way to windward, is to propel directly in the wind's eye. He points out the necessity of the greatest attention being "paid to the management of the helm at the moment of a squall or sudden gust of wind, or when a heavy breaker deadens the vessel's way when propelling against a gale, in which case the helm should be put in midships, when the helms-man will soon feel which way it ought to be turned to counteract the effects, and she will often be prevented from being forced from her course, by such timely and judicious management; but if every effort to prevent her falling off her course is ineffectual, no attempt must be made to bring her head again to the wind, until she has completely regained her velocity, which is done by steering for a few minutes about seven points from the wind, and then a lull or a moderate moment must be taken advantage of, to put the helm down, and then her course will easily be resumed. As long as a steam

vessel can be steered against the wind and sea there is no danger; this assertion, however, is not intended to convey the idea, that putting the head to the storm is always the best or safest position a steam ship can be kept in: on the contrary, she would be much safer and easier, unless the swell is so short that her length is sufficient to overcome its effects, with her head two or three points from the wind's direction."

In scudding before a gale, the rolling of a steam vessel is very quick, from her being relatively very narrow, which causes the paddles alternately to dip and rise out of the water, by which they sustain a great and irregular strain. In this case, as well as when the gale is on the quarter, the engine should be worked only with a moderate force. In scudding before a gale, the steam engine is, perhaps, less advantageous than in any other state.

There is no operation in the tactics of sailing vessels and steam vessels, in which there is a greater difference, than in changing the direction of their course: in tacking a sailing vessel, the forces which produce the action are complicated, and require skill in their management; while, in a steam vessel, the operation is perfectly simple, nothing being necessary but the use of the rudder. When it is necessary to turn a steam vessel in a short distance, the force of the engine must always be reduced, by which the space required for turning is diminished. An account is given of some experiments made to ascertain the difference in the time and space required to turn a steam vessel in a calm, round to the opposite direction, by stern-way and head-way. In the first experiment, "the steam vessel was at rest in a calm, the helm was put hard to starboard, the ship was impelled *a-head* by the power of the engine, which made thirty-six strokes per minute, when she described a circle, eight times her own length in circumference, having returned to the spot from whence she set out in four minutes and two seconds. The vessel being again placed in her original position, and the helm put a-starboard as before, the ship was impelled *a-stern* by the power of the engine; which made thirty-six strokes per minute, when she described a circle six times her own length in circumference, having returned to the spot from whence she set out, in three minutes and seven-

teen seconds; proving that in a calm, when no power acted upon her but the engine, the revolution can be performed in one-fourth less space, and in one-fifth less time, by what is called a *stern-board*." The second experiment was made, the helm being hard over, by suddenly "slowing the engine," after the vessel had made about one-fourth of a circle in turning round, the paddles being prevented from either impelling or impeding the vessel; with *head-way*, she arrived half her length within the situation she started from in nine minutes and nine seconds, having described a spiral arc of seven times her own length; with *stern-way*, she arrived her whole length within the situation from which she started, in six minutes and two seconds, having described a spiral arc of six times her length. These experiments show that the direction of a steam vessel is reversed in the least space by a *slow motion* and by a *stern-board*. The stern-board is, however, only recommended in moderate weather; in a storm it would be dangerous, and should be adopted only in great emergency.

Captain Ross accounts very satisfactorily for the difference in the effect of the head-way and stern-way in turning the vessel. He observes, "this is to be accounted for by the action of the rudder being more free from the influence of the eddy, or back-water, and by its being constantly kept, by the action of the water upon it, close over to the side of the stern-post, making a constant angle with the keel of about thirty-six degrees. All the water which acts upon the rudder, passes it thus from a-stern in a horizontal direction; while, on the contrary, when the vessel has head-way, the action of the rudder is diminished by the eddy which constantly follows the ship, to fill up the water which she displaces, and the water which acts upon it does not pass it in a horizontal direction, and that which the ship has passed over, by rushing up to join, filling up the water displaced by the ship, does not take the direction which has most power on the rudder."

Excellent remarks and directions are also given on the steerage of steam vessels; on their coming into, and going out of, harbours; on their service on a lee-shore; on their being taken a-back; on their assisting ships in distress, and on their service in case of accidents to boats.

The chapter on naval warfare by steam ships, is very excellent. The first consideration is the service of steam vessels attached to fleets: these vessels are supposed to be fortified so as for the hull and machinery to be protected at the distance of 600 yards. "This important and interesting portion of naval operations, has, by the introduction of steam, suffered a complete revolution, and in many instances its principles and practice are reversed. Formerly, the ship to windward was universally allowed to have the advantage, and to obtain the *weather-gauge*, was considered by a British officer the first step to victory; but now the ships or fleet to leeward will have a decided advantage, because it will always be in their power to bring the ships to windward to action, by doubling or trebling the number of steam ships to the chasing ships. For instance, we shall suppose that the hostile fleets each consist of twenty sail of the line, and that each ship has a steam boat attached to her; it is evident that if in both fleets the steam vessels were applied individually to each ship, the rates of sailing would be equal; but if the fleet to leeward applied *all* her steam vessels to one half of the fleet, that is, two steam vessels to each of the ten ships composing that half, the consequence must be, that they would come up with the rear of the weather squadron; for if their opponents did the same, they would tow away one half, and leave the other half unprotected, and would eventually be obliged to bear up to their assistance, when all that they had gained would be lost; but it would be always in the power of the chasing ships to return to their friends if too hard pressed. On the contrary, if the fleet to windward is chasing that to leeward, the whole would be before the wind, when the difference in sailing between steam vessels and sailing ships would be so little, if the breeze was fresh, that the event would not be much accelerated by that or any other method. In chasing, therefore, the weather-gauge is no advantage, yet the state of the wind and weather must be considered. If there is a fresh breeze, so that the rate of sailing between steam and sailing ships is nearly equal, let their positions be what they may, the chase will be longer, both in time and distance; and, indeed, it will often be judicious not to apply the auxiliary steam ship, until the wind has moderated so considerably, that

the application of steam would increase the velocity of the ship by one-third." This particular service of steam vessels appears to deserve peculiar attention, being one of the services, in which this country is likely to receive greater advantage from the application of steam to naval purposes than other nations.

It is recommended that the auxiliary steam-vessels should be large and heavy, that their momentum may the better overcome the shocks of the waves, and may preserve a regular strain on their consorts. Great attention should be paid to the steerage of the towed ship, to counteract any disadvantage from the manner in which the steam vessel carries its helm. "If the steam vessel carries a weather-helm, the ship should steer on the weather quarter, or a little to windward of the wake of the steam vessel, and the contrary if she carries a lee-helm; while, if a-midships, she should steer in her wake." A diagram is given to show the manner of stationing the auxiliary steam vessel, so as best to assist the sailing vessel, when brought into action. It is to be placed on the opposite side to the enemy, and attached to the ship by two tow-ropes, leading from the bow and stern of the ship to the fore towing timber-heads of the steam vessel, with a guy on each tow-rope leading to the bow and stern of the steam vessel. When it has performed its service to the ship it may take its own station as circumstances may require, to assist in the engagement. An important service of the steam vessels will be after the action, to take possession of the disabled ships of the enemy, and to assist ships of their own fleet: a conflict between the hostile steam vessels will then necessarily take place; and the importance of their own means of attack and defence will be apparent. So great indeed will their importance then be, that on them the extent of the result of a victory will in a great degree depend.

Captain Ross proceeds to consider the methods which will be employed in the attack and defence of hostile fleets composed only of steam vessels. He observes, that "as the flotillas will assume the character of a battle between armies, and their dispositions will be extremely similar; the main body of the flotilla will be composed of powerful vessels, whose paddles and machinery must be well protected; and there must always be a *corps de reserve* to supply the places of disabled vessels, and to sup-

port any part that may be broken and penetrated by the enemy." He describes, by diagrams, the order of sailing which he considers best for 60 sail of steam vessels. Three divisions are formed of 15 vessels in each, with a sufficient distance between them to contain two half divisions. Each of the three divisions is formed of four lines; the front line composed of four vessels, the second of three, the third of four, stationed as those in the first line, and the fourth of three, stationed as those in the second; the flag-ship leading the van. "By this arrangement each vessel is kept out of the wake of the next a-head; so that if any accident happens she will be in the best position either for assisting or avoiding her; it is also the best adapted for forming the various positions of attack and defence." The reserve is formed into two parts, stationed a-stern, "in the position the most advantageous to supply the places of the disabled vessels, and to protect the fuel transports, if any are with the flotilla." Captain Ross considers that "until steam vessels are constructed of a much larger size than at present, the line of battle will not be put in practice, but it will be formed more quickly from the order of sailing in two or three divisions than in any other way." Two methods of forming the line are described: the evolution most approved, as the least liable to be broken, is performed by the flag-ship falling into the centre of the first line, by two of the vessels of the second line taking their stations between the other vessels of the first line, and by the third vessel of the second line taking its station at the extremity of the first line: and by the third and fourth lines forming a line astern of the first line, the vessels being stationed so as to be between those of the first line. The fastest vessels are to be stationed in the rear, in the order of sailing, that the line may be formed in the shortest time. When the course is to be changed, either in the order of sailing or the line, the evolution is to be performed by the stern-board; by which much time and space will be saved, as shown by the experiments previously detailed. A single line, with the flag-ship in the middle, is formed into a double line most expeditiously by the vessels a-stern of the flag-ship propelling, and by those a-head using a stern-board.

"The modes of attack in an engagement between steam

vessels are more various, and will depend more on the skill both of the commander-in-chief and every captain individually, than in any former system of naval warfare; but there are also several general laws which are essential. The first is, that number, although inferior in force, will often have the advantage, and it will rarely happen that three small steam ships will not capture two large ones. While an engagement is going on between two and two, the unoccupied one will always be able to take a position to destroy the other, or to disable them, and decide the conquest; it will therefore be always the best plan of attack, to double on the adversary as soon as possible, in order to disable him immediately. To effect this the double column is necessary; and each ship of the enemy attacked by two, leaving the rest of their line unoccupied to repel an attack, the flotilla should be formed in a double line, in order that they might be better able to prevent doubling upon them, and that they, in their turn, might double on the assailants. This will also be the province of the ships in reserve, which should always amount to about one-fifth of the whole flotilla."

On convoys by steam ships Captain Ross observes, "one of the greatest advantages that Great Britain, as a commercial nation, will reap from the introduction of steam navigation, is the protection which it must afford to her commerce. At the first view of the subject, it may appear that a steam privateer might capture a merchant ship with great facility, by her superiority in velocity, and such is certainly the fact; but on the other hand, it must be taken into consideration, that the merchant ships will be protected by steam vessels, which must render the capture more hazardous, and all efforts to carry off the prize abortive. A convoy of 50 sail, bound to the West Indies, was usually protected by one or two ships of the line or frigates, and two or three small vessels; instead of which three or four steam vessels will be substituted; and this force will not only be much less expensive, but much more effective in every respect. They will, in the first place, be better able to keep the ships of the convoy within its limits, to tow up bad sailers, or ships that meet with accidents, and to take positions the best adapted for its protection. Admitting that a steam privateer should board and capture a merchant ship of the con-

voy, it is manifest that she cannot tow off the prize so fast as the protecting steam ship can follow both; and therefore a recapture must be the consequence." Whether the number of steam vessels which will be necessary are here underrated may appear doubtful; but that steam vessels will afford greater protection to a convoy than sailing vessels appears certain. The steam vessels will have the advantage of being supplied with fuel by the merchant ships. A diagram is given to show the order of sailing best adapted for the protection of the convoy; and many valuable observations are given on taking ships in tow, and other particulars relating to the conduct of the fleet.

The defence of our coast is the most important consideration connected with steam navigation. That steam would supply a power to France capable of invading our coasts, if defended only by sailing vessels, we readily admit; but when opposed by our steam vessels, the danger of such an attempt would be so greatly increased, as to render its design extremely improbable, and its execution, we consider, wholly impracticable. The facility of being always able, with steam vessels, to concentrate any force which might be required, would render a general engagement necessary, the result of which, whether we should obtain a complete victory or not, would necessarily so disable and diminish the invading fleet, as to render a retreat necessary.

The advantage afforded to our colonies by steam navigation will be very great. It will afford much greater protection from piracy, and greater security from shipwreck. Passages, at present dangerous, will be rendered safe. "The windward passage to Jamaica will, by the help of steam ships, be always attainable. The navigation of the Red Sea and the Persian Gulph, with the channels through the various straits in the passages to China, will be thus also rendered safe and easy."

At the conclusion of Captain Ross's excellent remarks on the tactics of steam navigation, the importance of establishing regulations for the equipment, appointment, and management of private steam vessels is shown. To the want of these he attributes the numerous accidents which have occurred. He recommends the appointment of inspectors at the different ports; who should be capable in all respects of examining the vessels

and the machinery, as well as of ascertaining the qualifications of those intrusted with their management. Such an arrangement would no doubt be attended with the most beneficial effects.

On the whole, the work of Captain Ross is by far the most valuable of any yet published on steam navigation: it is as comprehensive in its general view of the subject, as minute in its detail. Its excellencies are most apparent in those subjects immediately connected with nautical science; and its deficiencies may be chiefly discovered in those parts which relate to the design and construction of the vessels.

Highly gratifying is the conclusion, that the change which steam navigation is effecting in naval affairs, may be rendered on the whole favourable to this country; and that it requires nothing but the energetic application of the resources we possess, to its improvement, to maintain that superiority in naval power which we now enjoy.

ART. XVIII.—*Proposed method of making Rudders of Small Timber, for all Classes of Ships.* *By* MR. PARSONS *(formerly of the School of Naval Architecture).*

THE rudders of men-of-war are made with pieces of timber of various lengths, each piece being the whole thickness of the rudder athwartships; the principal piece, that which forms the head, extends as low down as possible; it is of English oak, and its content is frequently, in large ships, as much as 120 cubic feet: the other pieces are of elm and fir. The use of such large timber is very objectionable, as, independently of the difficulty experienced in obtaining it, there is a great probability of its not being perfectly sound, it being generally past its prime, and therefore subject to early decay; and a defect which does not absolutely destroy more than one cubic foot of timber, may be sufficient to condemn the whole 120 feet: the writer has seen such an effect produced by a cannon shot. To obviate these objections, the following plan is proposed for making rudders with smaller timber:—

It is proposed to make rudders of three thicknesses of plank or thickstuff, the outward layers, forming the sides of the rudder, being laid with the grain of the wood up and down, and the middle layer having the grain of the wood in a fore and aft direction, square to the foreside of the rudder; the strakes on either side being so laid that their joints shall alternately be opposite to the middle of the opposite strake, and their butts give shift to each other, so that each strake on either side may have fastenings in two strakes on the opposite side: the middle layer, that of which the grain is in a fore-and-aft direction, should be, at the head of the rudder, the thickness of the breadth of the tillar-hole, but in no case to exceed one-third the thickness of the rudder-head, and should taper from thence to the heel, where it may be about one-third or one-fourth the thickness of the rudder at that place; the tapering of the rudder in a fore-and-aft direction being taken wholly from the strakes forming the sides. The butt of each piece of the strakes forming the sides may be fastened with two copper bolts; and the edges of the strakes on each side of the butts may be dowelled; other dowels may be equally spaced on the edges of the side-pieces, if deemed necessary. All the fastenings of the rudder-bands should be copper through-bolts. The upper half of the rudder may be fastened athwartships, between the rudder-bands, with copper bolts, about two in each side-piece, in each interval between the bands, with as many additional bolts in the head as may be found necessary. The hoops at the head should be screw-hoops, to be tightened in case of any shrinking of the timber; though to avoid that, the pieces forming the head of the rudder might be of teak or African oak, which is also more durable; the remaining pieces may be of fir, excepting those in the two foremost strakes on each side, which should be of elm, and may increase in breadth at the heel according to the increase of the rudder; these pieces may be procured in one length.

Figs. 32 and 33 show the form and after part of the rudder of a first-rate; the side-pieces on the larboard side are represented by the dotted lines *a, a,* &c., the middle one being ten inches broad, and each of the others eight inches broad, making 26 inches, the size of the head of the rudder, in a fore-and-aft direction; the starboard side-pieces are represented by the

perfect lines *b*, *b*, &c., the head formed by two pieces, each thirteen inches broad, so that the joint of the two will be opposite the middle of the ten-inch piece on the larboard side; the fore-and-aft pieces forming the centre of the rudder, are shown by the lines *c*, *c*, &c., and the ticked lines *d*, *d*, &c.

The head may either be formed of three pieces on one side and two on the other, as shown in Fig. 34; or of two pieces on each side, as shown in Fig. 35; the edges of the pieces being dowelled together at every three feet.

By this mode of making rudders, the largest piece of timber of importance does not exceed 22 cubic feet, even for a first-rate; the requisite pieces can always be procured without difficulty, will be better seasoned, more free from defects, and may be of more durable and better timber in all respects. An important and most decided advantage will be the facility with which a spare rudder may be taken in every vessel; for the rudder may be put together complete, except the fastenings, with two or three spare bands fitted, the several pieces properly marked, then taken to pieces and stowed away between the beams of the gun-deck; it would then take but very little time to be put together again. The rudders of all vessels may be made according to this plan.

Art. XIX.—*Extract from the Report of the Commission charged by the French Government with the examination of Woods imported from Africa. (From the Annales Maritimes.)*

The timber imported from the coast of Africa appears likely to be in such general use, both in the royal dock-yards and in private establishments, that we consider the following tables of experiments, made at Brest, in June, 1828, by order of the French Government, to ascertain the strength and specific gravity of the wood, and also the diminution of volume it sustains in the process of drying, may prove interesting.

(1) *Results of Experiments made on the Woods imported from Goree and Sierra Leone.*

	(2) CAIL CEDRA, from Goree; Specimens taken from the First Importation.							CAIL CEDRA, from Goree; Specimens taken from the Second Importation.						
Designating No. of the Specimen	1	2	3			4		1		2	3	4	5	6
Weights supported, with the corresponding Flexure. Without Cracking.. Weight	—	285	330	150	595	210	150	325	540	260	340	360	380	330
Without Cracking.. Flexure	—	10	10	15	20	8	7	10	20	10	12	10	10	10
With Cracking .... Weight	—	590	605			590		659		495	530	640	636	560
With Cracking .... Flexure	—	20	27			7		37		20	20	25	24	20
At Fracture ...... Weight	690	620	695			660		650		640	710	645	700	750
At Fracture ...... Flexure	30	30	40			32		37		30	30	30	30	40
Total of the Weights ..	2665							4095						
Mean Weight	666							6825						
Total of the Flexures ..	132							197						
Mean Flexure ..	33							3						
Relation between these results and those of Oak Timber, taken as unity. Flexure	,825							,825						
Elastic Force	1,190							1,192						
Strength	,98							1,00						
Mean Weights of the Cubical Specimens. Sept. 1826. Top of the Tree..	1,095							—						
Sept. 1826. Butt	,928							—						
June, 1828. Top of the Tree..	,824							—						
June, 1828. Butt	,755							—						
Mean Weights of Cubes from both top and butt. Sept. 1826	,914							—						
June 6th, 1828..	,841							—						
Weight lost in 17 Months	,073							—						
Diminution of Volume in a direction perpendicular to the fibre, in a period of 17 months. Top..	. 2							—						
Butt..	2							—						

(1) The weights in these tables are expressed in kilogrammes, and the measures in millimetres: the kilogramme is ,453 of a pound avoirdupois, and the millimetre is ,00328 of an English foot.

(2) The first specimen broke without giving any warning; the others commenced by cracking, but broke almost immediately afterwards. The fracture was short, especially in the specimens taken from the head of the tree.

Results of Experiments made on the Woods imported from Goree and Sierra Leone.

		(1) GONAKIER, or *Mimosa Nilotica*, from Goree.			(2) DETHARD, from Goree.					(3) TURTOSA, from Sierra Leone		
Designating Number of the Specimen		1	2	3	1	2	3	4	5	1	2	3
Weights supported, with the corresponding Flexures. Without Cracking	Weight	900	—	—	—	490	440	490	470	500	800	915
	Flexure	22	—	—	—	22	20	20	20	10	12	20
With Cracking	Weight	990	—	1,082	—	660	540	620	620	870	990	—
	Flexure	32	—	30	—	37	30	40	40	20	22	—
At Fracture	Weight	1,185	800	1,200	—	740	660	720	700	915	1,080	1,250
	Flexure	42	25	40	50	90	50	75	60	30	40	42
Total of the Weights		3185			2820					3245		
Mean Weight		1062			564					1082		
Total of the Flexures		107			325					112		
Mean Flexure		36			65					3		
Ratio between these results and those of Oak Timber, taken as unity.	Flexure	,90			1,350					,925		
	Elastic Force	1,504			,914					2,060		
	Strength	1,56			1,036					1,53		
Mean Weights of the cubical Specimens. Sept. 1827.	Top of the Tree	1,312			,925					1,030		
	Butt	1,291			,920					1,010		
June, 1828.	Top of the Tree	1,070			,768					,878		
	Butt	1,060			,771					,902		
Mean Weights of Cubes from both top and butt.	Sept. 1827	1,301			,9225					1,020		
	June 6th, 1828	1,065			,7695					,890		
Weight lost in 8 Months		,236			,153					,132		
Diminution of Volume in a direction perpendicular to the fibre, in a period of 8 Months.	Top	—			2,5 to 3					3 & 4,5		
	Butt				2,5 to 3					3 & 4,5		

(1) This wood gave several slight cracks before breaking. The fracture was of considerable length, and the grain of the wood appeared closely interwoven.

(2) The greatest diminution of volume was on the side of the specimen the furthest from the heart of the tree. The fracture was of considerable length. The specimen No. 3, proved defective. The specimen No. 4, was placed with the side nearest the heart of the tree upwards, and it began to crack at a Flexure of 70 millimetres. The specimen No. 4, was placed in the opposite position, with the heart downwards, and broke almost instantaneously.

(3) The first specimen broke short, and with little warning; the two others cracked some time before breaking, and the fracture was of considerable length.

"The Cail Cedra, though less flexible, is tougher than oak; and being as strong, without being heavier, may be quite as advantageously employed in naval construction as that wood; the greater uniformity of its grain, will probably enable it to resist decay for a longer period; its red colour renders it preferable both for the cabinet-maker and the inlayer, although it is far from possessing the same beautiful vein as mahogany.

"The Gonakier, almost as flexible as oak, and at the same time possessing one-half more strength and toughness, is better calculated for the frames of ships: its hardness and weight must no doubt render it a very durable wood; the appearance of its vein is very similar to that of ash, but it is of a redder colour; it is difficult to work, and particularly so to polish. An attempt was made, but without success, to make sheeves for blocks of it.

"The Dethard, of equal strength with oak, is more flexible, but has not such elasticity; its fibres lie in concentric layers, separated with a very slight silver grain; it appears very well adapted for planking, and as a substitute for compass timber.

"The Turtosa, which has rather less flexibility than oak, is superior to it in every other respect. This wood, with the Gonakier, and also all the hard woods from Guiane, rend easily when exposed to heat; they therefore require care to be taken of them when they are seasoning. The Turtosa is nearly of the colour of pear-tree.

"In recapitulation, these species of woods may be usefully and advantageously employed in naval construction, if they can be procured of necessary form and dimensions."

The specimens experimented on were parallelopipeds and cubes. The parallelopipeds, which were the specimens used for determining the strength, were five centimetres square, and the points of support were one metre distant from each other. The strain was applied in the middle, between the two points of support.

Art. XX.—*On the Means of Preventing Ships from Arching.* *By* Mr. W. Henwood.

That indication of weakness in ships, known by the terms arching and hogging, is a consequence of the buoyancy of the water at the ends of a ship, being less in proportion to the superincumbent weight of the hull and its contents, than the buoyancy in midships. The gravity of the extreme ends and midship part of a ship, and the corresponding upward pressures of the water, being very unequal, and variable forces which act incessantly on a ship from the instant she is first made to float, must necessarily impair her strength, and make her arch in a greater or less degree, however strong and well built she may originally have been. The employment of means to diminish the extent of this evil, and to retard its progress, is an object demanding the attention of ship-builders.

It is well known, that about fourteen years ago, a very important method of strengthening ships, by a diagonal framing, was proposed by Mr. (now Sir Robert) Seppings. The principle of the system of diagonal framing in ships is founded upon one of the simplest propositions of geometry, and cannot therefore be invalidated. Its practical utility appears, at the period just mentioned, to have been manifested, by experiment, in a very satisfactory manner.

It is related by Mr. Knowles, in his 'Inquiry into the Means of Preserving the Navy,' that, "to prove the efficacy of the plan of trussing ships, it was tried in a temporary manner in the Justitia, of 74 guns, built in Denmark in 1777, and captured at Copenhagen in 1807: the ship being old, the materials were in general decayed, the fastenings loose, and she was so much broken in her sheer, that when taken into dock upon straight blocks, an alteration took place of two feet three inches and a quarter, in each half of her length; and when undocked, with the trusses placed, she broke one foot two inches and five eighths. Twenty-four hours produced a further breakage of two inches and five eighths. The temporary trusses in the hold were then disengaged, and an alteration of six inches im-

mediately took place in the sheer of the ship; when the trusses, which were placed diagonally in the ports, were taken out, she broke four inches, thus bringing her to her original sheer. A great compression of the diagonal pieces was everywhere visible."

Mr. Knowles has not stated in what particular manner or position the temporary trusses in the hold were fixed; but as, if they had been placed on a surface, or in a position which more nearly coincided with a horizontal than with a vertical plane, it would be utterly impossible to account for the good effect they were found to have produced, it is proper to mention that these temporary trusses were placed in midships, under the beams, in a longitudinal and vertical plane.

In order clearly to understand the nature of the effect intended to be produced by the diagonal framing in ships, suppose four planks joined together at their ends, so as to form a square frame, ABCD, Fig. 36, Pl. 4; and let the side AB be fastened to the upright pillar EF. It is evident, that however securely the four planks may be connected at their ends, the force of gravity will cause the side CD to descend, so that the points D, C, will fall below the horizontal lines through A and B. If a truss-piece be fitted diagonally from B to D; or, which is the same thing, if a brace *ab* be fastened to AD and DC, parallel to the diagonal AC, and a truss-piece *t*, be placed perpendicularly to *ab*, it is equally plain that the side CD will not descend, because its weight will be sustained by the truss-piece *t*. This illustrates the principle of diagonal framing. The resistance of the truss-piece *t*, to the descent of the side CD of the square frame, is precisely similar to the resistance which it is intended the truss-pieces of a diagonal frame should present to the arching of a ship.

If the side AB of the square frame, instead of being fixed vertically, were fixed so that the plane ABCD would be inclined to the horizon 45 degrees, the effect of gravity on the frame ABCD would be the same as if its gravitation was caused by two equal forces acting on it, one perpendicular, and the other parallel, to the plane. And generally, if the plane ABCD be not vertical, the effect of gravity will be the same as if two forces together, equivalent to the weight of the frame, acted

on it, one perpendicular and the other parallel to the plane, the former being in proportion to the co-sine of the plane's inclination, and the latter to the sine. Were the side AB to be fixed so that ABCD would be horizontal, the whole force of gravity would act perpendicularly to the plane; and the weight of the truss-piece *t*, and diagonal brace *ab*, would accelerate, and not obstruct, the descent of the side CD.

To apply these remarks;—suppose a ship of rectangular form, with an entirely flat bottom, and perfectly plane and vertical sides. Also, suppose the weights on board such a ship to be so distributed that she would have the same tendency to arch as a ship of equal magnitude, of the common form, stowed as ships usually are. If a system of diagonal braces and trusses were applied to the sides of this rectangular ship, they would be brought into action by the tendency to arch, in exactly the same manner as the brace and truss-piece of the square frame ABCD, when fixed to the vertical pillar EF: that is to say, if the substance of which the braces and trusses were formed, was perfectly hard and inflexible, they would actually prevent the ship from arching.

If braces and trusses were placed on the bottom and ends of such a ship, they could not possibly be brought into action, one upon another, by the tendency to arch; and they would have the effect of increasing, instead of diminishing, the arching. Let the angles of the rectangular ship be now supposed to be cut off, and her sides, bottom, and ends connected with curved pieces of timber: her form will be assimilated to that of ships, those of the line especially; a large portion of their sides, above and below the water's surface, being nearly vertical, and a considerable part of the surface of their holds being very nearly, or quite, horizontal.

The angles of elevation of a number of equidistant lines drawn in athwartship and vertical planes from a line ranging through the upper ends of the braces, in the hold of a first-rate, to a line passing through their lower ends, have been measured, and a mean of them taken. And as the elevation of each of those lines must be the mean elevation of the arc of which it is the chord, the mean elevation of all of them must be the mean elevation above the horizon of the whole surface

upon which the diagonal framing is placed. The mean angle of elevation thus found does not exceed 40 degrees. So great a deviation from a vertical position of the surface upon which the braces are situated, shows clearly that the tendency of a ship to arch, by whatever means it is opposed, cannot be advantageously resisted by diagonal framing applied in the hold.

A few remarks will now be made on the mode of constructing diagonal braces. Those usually placed in ships are in general formed by three timbers, about 14 or 15 inches square, and about 15 or 16 feet long. The two upper timbers are united by means of a piece of timber wrought upon them and bolted to them. The middle and lower timbers are placed side by side, for about five feet of their length, and are bolted together.

Suppose the brace *ab*, Fig. 36, Pl. 4, to be formed in this manner, and applied to a square frame ABCD, of corresponding dimensions, fixed vertically; and a truss-piece *t*, fitted also in the same manner as the trusses of a ship. According to a just and well-known axiom, the transverse strength of such a brace is only that of its weakest part, or the strength of the connexion produced by the two bolts which unite the middle and lower timbers: and as it is upon this transverse strength of the brace the stiffness of the frame entirely depends, such a brace, formed of three or four pieces of timber, so united together that the transverse strength of the whole brace must be insufficient to preserve it from a tendency to bend considerably by its own weight, when fixed on the frame, can have very little effect in preventing the deflection of the side CD, compared with what it would be if formed of one inflexible timber.

If braces like those in the hold of a ship, by being fixed on the perpendicular part of the sides, could be submitted to such a strain as has been supposed to be brought on one of such braces, when fixed on the square frame ABCD, there is much reason to believe they would be incapable of enduring it for a length of time. The greater part of the diagonal framing in ships' holds, however, cannot be subjected to such kind of action, as it is applied on a surface much more nearly horizontal than perpendicular to the horizon.

The circumstance of the braces and trusses in ships being

connected with the sides, does not affect the foregoing reasoning. It is essentially necessary that the square frame ABCD, with the brace and truss-piece fixed to it, should be incapable of arching by its own weight, in order that it might be capable of sustaining an additional weight on the side CD without being deflected. And, in the same manner, if the diagonal framing of a ship could be detached from her sides, and the whole of it, by some means or other, connected precisely in the form and position it had in the ship, and supported at the middle—if this diagonal framing, could not then maintain itself in this its original form and position, it is impossible to suppose it could be of the smallest utility in preventing the deflection of the extreme ends of the ship.

It cannot be supposed that ships arch gradually from the place of their midship sections towards their ends. Arching appears, in general, to commence from the points where the opposing forces—the vertical pressure of the water on the bottom, and the superincumbent weight of the ship—are equal to each other. The surface upon which the diagonal framing is situated between those points and the ends of a ship, is much more nearly parallel to the horizon than the midship part of the hold; and consequently a diagonal framing, when placed in the hold, is the least calculated to prevent arching towards the ends of a ship; where principally, if not alone, this effect takes place. In the midship part of a ship there may occasionally be a tendency to sag; and it is probable this is usually the case in the immediate vicinity of the main-mast.

Could braces and trusses be so fixed on the sides of ships that they would counteract the arching in an effectual manner, an important advantage would doubtless be obtained. It has clearly been proved that no diagonal framing can possibly prevent arching, unless it is applied on a surface nearly vertical. And the circumstance of the diagonal trusses in the Justitia, of 74 guns, referred to at the commencement of this paper, having been placed in a longitudinal and vertical plane, and having been found, when so placed, to produce the desired effect of diminishing the arching, shows that the foregoing reasoning is confirmed by experiment. That portion of a ship's sides which most nearly approximates to a vertical plane, is that which is

adjacent to the line of floatation, or the part between wind and water. It is considered that a diagonal framing might be placed on this part of the sides of ships, which would effectually resist the arching.

It is proper to observe, that as this part of a ship's sides is more powerfully acted on than any other, when the ship is much inclined from the upright position—since a considerable portion of the whole weight of the topsides, decks, guns, masts, rigging, &c., acting downward on that part of the lee-side which is above the water, concurs with the pressure of the fluid below to strain the side transversely with great force—it appears requisite the stiffness of the sides of ships, between wind and water, should be as great, at least, as the stiffness of any other part of their sides. When a ship is inclined about 17 degrees from the upright position, the effect of the weight above water is the same as if one-fourth part of it acted in an athwartship direction, parallel to the decks, to bend the sides of the ship to leeward, and the remainder in a direction perpendicular to the decks; the former being in proportion to the sine of 17°, and the latter to the co-sine. The frame timbers are the only effective means of producing this stiffness to the sides of ships in the vicinity of the water line.

If a system of diagonal braces and trusses could be applied on the sides of ships in the vicinity of the water line, they would counteract the tendency to arch in the most effectual manner; and they would, at the same time, afford an increase of strength to this part of the sides. Such a system might, it is thought, be advantageously substituted for the inside planking below the lower deck ports: the powerful longitudinal connexion, formed by the wales and planking on the outsides of ships, and by the shelf-pieces, water-ways, and planking on the insides, would render the small diminution of longitudinal binding, which would be occasioned by such a substitution, unimportant; and it would be more than compensated by the strengthening of the sides to support a transverse strain.

A general description will now be given of the manner in which it is considered that braces and trusses might be applied with advantage on the most nearly perpendicular part of the sides of a two-decked ship. Fig. 37, Pl. 4, is a represent-

ation of the midship part of the side of a ship of the line, with the diagonal braces, and decks, and lower deck ports.

The braces are inclined at an angle of 45 degrees to an athwartship and vertical plane. Each of them might be formed of one straight piece of thickstuff, of about the same thickness as that for the gun-deck clamps. The upper ends of these braces could be placed in the angles formed by the under side of the upper-deck clamps, (middle-deck clamps in three-decked ships,) and the fore sides, or the after sides, of the gun-deck ports, according as the braces might be afore or abaft the middle of the ship. Their lower ends could be placed about six or seven feet below the orlop-deck, in midships, rising gradually forward and abaft, so that the extreme ends of each brace might be nearly in the same vertical and longitudinal plane. The ends of each brace could be reduced to the thickness of the upper-deck clamps: this would facilitate the operation of bringing them into contact with the frame timbers, in the usual manner of working plank. The lengths of these braces would vary from about twenty to thirty feet; and it would be proper to make them of as great breadths as the thickstuff of which they should be formed would admit; because their inflexibility increases as the square of their breadth, and only in the simple ratio of their thickness.

The trusses should be as thick, and about as broad, as the braces, and placed at right angles to them. The upper ends of the upper range of trusses could be disposed under the clamps, and at the opposite sides of the ports, to correspond with the upper ends of the braces. The lower trusses could be placed in straight lines with the upper ones, so as to form, with the braces, a regular series of equal squares.

As, by placing the upper ends of the aftermost braces under the upper-deck clamps, they would be very short, the aftermost two or three might be placed under the quarter-deck clamps; (upper-deck clamps in three-decked ships;) as the clamps, shelf, waterway, and spirketting of the roundhouse, by extending several feet further forward than these braces, would make the sacrifice of the after end of those clamps, and the after end of the spirketting, of no consequence whatever.

Short pieces of thickstuff could be wrought between the

braces and trusses, to support the beams, and to receive the shelf-pieces and water-ways;—those of the gun and orlop decks. These pieces would be situated exactly underneath the lower-deck ports: they should be coaked to the frame timbers, to support the pressure of the decks and guns. The vacant spaces between the braces and trusses might be partly filled with four-inch planking, and partly left open, to admit air to the frame timbers. Such a system of braces and trusses would require a comparatively small quantity of metal fastenings; the bolts and treenails driven through the outside planking, would naturally form its principal security.

If a diagonal framing were to be placed on the upright part of the sides of ships, it might become a question whether it would still be proper to apply planking, or riders of some description, in their holds.

Planking, or riders, in the holds of ships, can scarcely be of any other use than, in conjunction with the outside planking, to prevent working of the abutments of the frame timbers, and to increase the longitudinal stiffness of the sides. But as the easiest and most effectual way of preventing the working of the frame timbers is to render the frames inflexible in themselves, by securely coaking the timbers to each other, it would be advantageous, it is considered, to unite the frame timbers of large ships, in the manner described in Art. 2, No. 5, of this work, which would ensure a resistance sufficient to prevent this working altogether. The expediency of increasing the longitudinal stiffness of the sides of ships may appear, from considering that when a ship is inclined, the pressure of the water on the lowest part of the lee-side is greater than on any other part of her bottom, and tends to strain the ship considerably when the weights in the hold are not sufficiently great, or are not distributed in such a manner as to cooperate with the strength of the side to resist it. And as a ship, when on shore, generally rests on that part of her bottom which sustains the greatest pressure of the water when she inclined under sail; and as the preservation of her form, in this circumstance, must depend principally on the longitudinal inflexibility of her bottom, it seems proper, on this account, to strengthen the sides of ships, at the place of the greatest pressure of the water, when they

become heeled to an average inclination. It is, therefore, worth while to consider what is the best method of applying timber or plank in the holds of ships, to produce this particular kind of strength.

It is most evident that if pieces of timber were applied on the frame timbers, in a ship's hold, in an athwartship direction, they would have no effect at all in increasing the longitudinal stiffness of the sides. It is equally plain that if they were placed so as to form an angle with an athwartship and vertical plane, they would then augment this inflexibility of the sides in proportion to the magnitude of the angle of inclination; and, accordingly, they would produce the greatest degree of longitudinal rigidity only when applied in a fore-and-aft direction. If it was required that the rectangular and flat-bottomed vessel, formerly supposed, should be so strengthened, that if she were sustained in midships, as a lever on a fulcrum, with the ends unsupported, she would not arch, it would be wrong to fix a quantity of timber on her bottom, in an athwartship direction; or, indeed, in any other direction than fore-and-aft. The best way, therefore, of applying timber or plank in the holds of ships is to place it longitudinally.

To render ships less liable to sustain injury by lying aground, and to prevent their being strained when there is an unusual excess of buoyancy on a portion of the lower part of their bottoms—through a large deficiency of water or other weights on board—a series of well-connected pieces of timber, of as great lengths as could generally be procured, might be wrought in the lower part of their holds, in the same situations and direction as binding strakes. Each series of timbers might be united at the ends of a ship by means of the breasthooks and transoms; and as they would be firmly bolted to the sides, they would be well adapted to resist whatever degree of straining or working the lower part of the hold might be subjected to, from the pitching and 'scending motions, or from other causes. And, if binding strakes were to be wrought over the abutments of the frame timbers, on that part of a ship's hold which is elevated more than forty-five degrees above the horizon, and which is brought nearly into a vertical position when the ship is much inclined under sail, an addition of longitudi-

ual stiffness would be supplied whenever the stiffness, afforded by the planking on the more nearly perpendicular part of the sides, is rendered less subservient to strengthen the ship, through her being inclined considerably from the upright position.

The outside planking near the keel, or planking on the flat part of the hold, must produce but little longitudinal stiffness in a ship, compared with that which would be produced by pieces of timber of considerable thickness; since the strength of planking is to that of timber of the same length and breadth, as the square of the thickness of the planking is to the square of the thickness of the timber. Also, as timber is always placed in ships in its natural form, without being forcibly bent, as plank generally is, into a shape from which the elasticity of its fibres must, in many cases, have a strong tendency to produce a change, it is obvious that timber of square dimensions must be much better adapted than plank can be, to prevent a ship from being injured by a partial and violent pressure on the flat part of her bottom.

It is thought that the iron ballast of ships, which is at present of no other use than to increase their stability, might be rendered available for the purpose of augmenting the strength of the lower part of their sides. If a part of a ship's ballast consisted of pieces from fifteen to twenty feet long, three or four inches thick, and about six inches broad, it might be substituted for the lower longitudinal timbers in midships. Such pieces of ballast could be fastened to the frame timbers with bolts or screws; and by their buts being made to give shift to each other, they would afford as great a degree of longitudinal strength to the lower part of the sides of ships as could be required.

If a diagonal framing was to be placed on the upright part of the sides of a ship of the line, and if her decks were to be formed of thickstuff, as described in Art. 2, No. 5, the cost of her hull would be very greatly diminished.

Art. XXI.—*Remarks suggested by the Trials of the recent Experimental Squadron, consisting of seven new Ships of War.*—*By* Mr. Henry Chatfield (*formerly of the School of Naval Architecture*).

In the month of October, 1824, public attention was first directed to the movements of an experimental squadron, which consisted of three corvettes, each carrying eighteen[1] 32-pounder carronades; and it will be recollected, that every intelligence respecting the comparative merits of those ships was received with an avidity, and repeated with a warmth of interest, which bore testimony to the importance attached to the issue of that trial; not only in naval circles, but by the community at large. The rival vessels were, the *Orestes*, *Champion*, and *Pylades*, constructed on the respective plans of Captain Hayes, R.N.; Dr. Inman, Professor of the Royal Naval College and School of Naval Architecture; and Sir Robert Seppings, one of the Surveyors of His Majesty's Navy.

The object of the series of experiments entered into, was to decide on the superiority of one or other of the systems on which the vessels had been designed; but such were the alternations of success, in consequence of repeated alterations, that each ship in its turn had an advantage over the others; and, finally, nothing specific was determined, as regards the comparative merit of the forms of the ships' bodies.

In the recent experiments, which were conducted on a much larger scale, and which therefore excited considerably more interest than the former, the same projectors have again brought their plans into competition; and another naval officer, Wm. Symonds, Esq., commander,[2] has been added to the list of experimental constructors.

It is highly desirable to describe the modes pursued by the various projectors in preparing their draughts, that the points on which they differ might be ascertained, and undergo the test of theoretical investigation as well as experiment; but, in

[1] The real force of these vessels, is sixteen 32-pounder carronades, and two 9-pounder long guns.—H. C.

[2] Now Captain Symonds; having been preferred to the rank of Post Captain.

the present instance, this cannot be accomplished. In the first place, because Captains Hayes and Symonds have not given publicity to their views of ship-building; and secondly, because the author of these remarks would be unwilling (as a member of the School of Naval Architecture) to draw a comparison solely between Sir Robert Seppings's system and that which is followed by Professor Inman. It may, however, be proper to observe, that the situation in which Dr. Inman stands, owes its origin to a plan laid down (1808) by the Commissioners of Naval Revision, for establishing a School of Naval Architecture at Portsmouth Yard. This plan was first carried into effect in 1810; since which time, it has been the peculiar province of Dr. Inman to teach the application of mathematics to the theoretical construction of ships, and to explain the principles which have already been fully demonstrated in standard foreign works; and whatever is done by him may be considered truly philosophical, and quite consistent with the present state of naval science. From the experience the Rev. Professor has had during that portion of his valuable time which has been devoted to furthering the objects of the School of Naval Architecture, he now, in this early day of the institution,—early compared with the time requisite for reducing English naval architecture to a perfect system,—stands before the world; open to the scrutiny of opposite principles and contending interests, and anxious to seek, rather than shrink from, a most critical investigation of every principle on which he professes to act.

We will now give the names, dimensions, &c., of the ships which constituted the recent experimental squadron, with a very brief outline of their relative merits in sailing; appending some general observations, which may be considered pertinent to the subject.

	28-gun SHIPS.			CORVETTES, carrying eighteen 32-pounder Carronades.			
	Tyne.	Sapphire.	Challenger.	Wolf.	Columbine.	Acorn.	Satellite.
	Feet. In.	Feet. In.	Feet. In.	Feet. In.	Feet. In.	Feet. In.	Feet. In.
Breadth extreme	32 6½	33 8	32 8½	30 6¼	33 2¼	30 6	30 6
Length on lower deck	125 0	119 0	125 7½	113 4½	105 0½	112 0	112 0
— of keel for tonnage	106 7⅞	100 7½	105 11½	91 8¼	84 0⅛	92 1⅜	92 1⅜
Depth in hold	9 9	8 0	9 0¾	7 10¾	7 11	7 10	7 10
Burthen, in tons	600	605 60/94	602 89/94	454 25/94	492 15/94	455 74/94	455 74/94
		Feet. In.	Feet. In.	Feet. In.	Feet. In.	Feet. In.	Feet. In.
[1]Draught of water forward	16 2	15 0	15 11	14 7½	14 4	13 10	14 5
Ditto abaft	16 6	15 10	16 3	14 7½	14 11½	14 11	15 0
Height of midship port	5 2	5 0	5 6	5 4¾	3 11½	6 0	5 5¼
[2]Draught of water forward	16 11	15 8	16 7	15 0½	14 7½	14 9	14 10
Ditto abaft	16 8½	15 11	16 7	14 8	15 0	15 0	18 3
Hight of midship port	4 9	4 7	5 0½	5 2¼	3 9¾	5 5¾	5 3¼
By whom designed	Sir Robert Seppings.	Professor Inman.	Captain Hayes.	Captain Hayes.	Captain Symonds.	Sir Robert Seppings.	Sir Robert Seppings.

[1] When equipped for Channel service, or for 4 months'.
[2] When equipped for foreign service, or for 6 months'.

The trials with the above ships were conducted by Rear-Admiral Sir Thomas Hardy, whose opinion on their relative merits has not met the public eye. There is no question but everything was done that could be done, to arrive at the characters of the vessels; and the universal feeling in the squadron, that the Commodore would do justice to *all*, leaves the impression that the direction could not have been in better hands. With respect to the order of superiority in the sailing qualities of the several ships, there seems to be but one opinion; although few are agreed on the extent to which any vessel actually proved herself to be superior or inferior to others. If a mere knowledge of how the ships sailed, &c., during the times of trial, were the desideratum, the information is doubtless to be found in the Admiral's report. Journalized accounts, throughout the squadron, have been found to correspond in the general tendency of their contents, but not so nearly as if some previously-concerted plan had been followed on board every ship.

The writer of these remarks acknowledges having derived much professional benefit from having been at sea; he sees many things, connected with the subject, more clearly than before he embarked; and the little experience he has had, gives him some confidence in setting forth his opinions. And here it must be confessed, that the trials were not conducted in a manner that could be made available to the general principles of naval architecture; and that nothing further can now be educed than what may result from general remarks.

Observations relative to the experiments should have been taken *simultaneously* by every student of naval architecture [1] in the squadron, and no circumstance that could possibly affect a ship's sailing have been omitted under the head of "Remarks." This, however, was not methodically attended to; moreover, as the termination of a trial was not known till the Commodore made signal to "close round the Admiral," it then became necessary to take the bearings of the ships with the greatest possible promptitude, and to estimate distances "by

[1] There was a student of naval architecture on board every ship in the squadron, whose duty it was to report on the characters of their respective ships, and to remark on the sailing qualities of the vessels generally.

the eye," in order to obtain the bearings and distances of the whole of the vessels before their relative situations were much altered, in consequence of "bearing up" to close round the Admiral.

Diagrams were occasionally made, during the day, by the students; but there was no correspondence between the students as to the time of making them, and the conditions. It would be extremely easy for persons on board each ship to take the bearings of the others, by signal, simultaneously; and, this being done, the pennant of any particular vessel could be made, and her distance from the rest correctly estimated. Repeating this with the whole in succession, as quickly as convenient, little or no difference would be found in the diagrams of the several observers.

Distances may be correctly estimated, by knowing the height of a ship's masts above the water, or above the hull, and measuring the subtended angle with a quadrant; for, if we consider the height of the masts as the height of a right-angled triangle, and call it *radius*, we have the following proportion (the angle at the vertex of the $\triangle$ being the complement of the angle measured); viz., *rad.* : *co-tang. of observed* $\angle$ :: *height of masts* : *required distance.* Putting this equation into logarithms, we obtain the required distance.

It might be worth while to try what practical correctness would be found in determining distances by *sound.* The time that elapses between the instant of seeing the flash or smoke of a gun, and hearing the report, may be measured, in ordinary cases, with tolerable accuracy; and the distance of an object from the point of observation is readily ascertained, by knowing the rapidity (1142 feet per second) with which sound travels. By counting one's pulsations, previously comparing them with true time,—or by placing a watch to the ear,—it is neither necessary to have the assistance of a second person, nor to employ a stop-watch, to note the time intermediate between a flash and the consequent report.

It is generally admitted, that square-rigged vessels sail within *six points* of the wind: if so, *two* points over the lee-bow and the weather-quarter will give the direction in which all ships equally to windward will be found; and, allowing two vessels to be so circumstanced, they will (if there be no differ-

ence in their sailing "on a wind") meet at the same point, provided they be on (converging) opposite tacks. Guided by this principle, and taking the bearings and distances[1] as carefully as circumstances would admit, the comparative sailing of the experimental ships may be spoken of, generally, as follows, during the first series of experiments; viz.—between April 5th and May 27th, 1827.

In moderate weather, the Columbine and Challenger were found to be decidedly the most weatherly vessels of the whole, Columbine having rather the advantage, perhaps, of Challenger. The Sapphire, Satellite, Wolf, and Acorn, had such alternations of success, that it is difficult to say which was the superior ship: at the same time, if the little difference that was evinced entitles them to an order of superiority, they would stand as they are here named. The Tyne was considerably inferior to the rest.

In rough weather, Sapphire had the advantage on all points of sailing. Challenger was a little superior to Columbine, and Columbine had the advantage of the other corvettes. Satellite, Wolf, and Acorn, were still too nearly equal to justify any marked difference in a report of their relative merits.

The Tyne left the squadron before the end of the series of trials which established the above characters of the ships, and returned to Portsmouth, where she underwent extensive alterations. And as the projectors of some of the other ships considered that their vessels also might be improved, the squadron was fitted out for a second experimental cruize, with four months' stores and provisions, as before.

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[1] An easy method of constructing diagrams, is to provide a circular piece of card, of any convenient size, with the cardinal points marked upon it. Let two lines be drawn at right angles to each other, and let the card be so applied on them, that one of the lines shall represent the direction of the wind; the other will, of course, show the direction in which all ships equally to windward will be found. The observer should then set off the bearings of any number of objects, by means of the card, and join the points with the intersection of the two right lines. Upon the directions thus obtained, set off the estimated distances of the objects: this will give their situations, from which draw perpendiculars to the direction of the wind. Their distances from the point of intersection will show how far the ships are to windward or to leeward of the observer; or, their distances apart will show the same thing of each other.

We should here enter minutely into the nature of the alterations made, and, after the next series of trials, compare their actual effect on the ships' sailing qualities, with the results anticipated. But it is hardly necessary to observe, that, in order to do this, very correct sets of drawings of the whole of the ships should be got together; and every alteration, however trifling, should be pointed out and discussed, by the various projectors, among whom a perfect freedom of communication, as regards their particular views, hypotheses, or experience, is quite indispensable. Unfortunately, the experimental ships bore too much the character of rival vessels.

The squadron left St. Helen's, the second time, June 30th, and made a voyage to Lisbon, where they arrived on the 19th of July. On the passage, there were two trials off Scilly, on a wind; viz., on the 3d and 5th of July. On the 6th of July, the ships steered a S.W. course, and continued to run for the Tagus until the 16th. Experiments were then made, for three successive days, on a wind; and on the 19th, the ships anchored in the Tagus.

The relative merits of the ships were a little changed,—in consequence of the alterations that were made after the first cruize. Columbine was certainly improved, and also the Acorn; but Sapphire did not behave so well as before. The Tyne, though much improved, was inferior to all the other ships until her arrival at Lisbon; but, after leaving the Tagus (July 31st), she held fair competition with the rest of the squadron, especially against a head sea, with fresh breezes. Upon the whole, we may speak of the ships as follows, after the second cruize:—

In moderate weather, Columbine behaved decidedly best, and Challenger next; and all the others were very nearly equal. In rough weather, Columbine retained the advantage, but it was not great. Challenger and Acorn were very equal, and may be considered rather superior to Tyne, Satellite, and Wolf. Sapphire cannot be judged of in this second series of experiments, in rough weather, for there were only three trials in strong winds (August 14th, 16th, and 17th); and on each occasion, something occurred either to prevent her joining in

the experiment, or to discontinue the trial. On the 14th, she carried away her jib, when she was doing as well as any ship in the squadron; on the 16th, she "bore up," about two hours after the trial had commenced; and on the 17th, she did not come up with the other ships to make trial. On the 26th of August, the fleet again anchored at Spithead.

It now became a question, how the ships would sail when deeply laden, and what were their capabilities of stowage. To prove these points, every vessel was ordered to take *six months'* stores and provisions, of every denomination, on board; under which circumstances, they proceeded to sea (Sept. 24th). They were only one day out; for they returned to their former anchorage, at St. Helen's, the same evening, owing to the state of the weather. On the morning of the 25th, the squadron again made sail, and had a trial that day; but Tyne met with an accident in the Channel, at night, which made it necessary for her to return into port, and she did not afterwards join the squadron.

On the 24th and 25th, there were fresh breezes and little sea. Columbine retained her former advantages over the whole, but Challenger did not.

The general results of their third cruise appear to have been, that Sapphire and Tyne were nearly equal on the 24th and 25th, on which days there were fresh breezes, with but little sea, and decidedly superior to Challenger. After Tyne left the squadron, Sapphire retained her superiority over Challenger. Wolf (as well as Challenger) lost her comparative rate of sailing; but Columbine did not lose her former advantages, except in heavy weather against a head sea, under which circumstances she was excelled by the Acorn. Upon the whole, there was no great difference between Columbine, Acorn, and Satellite, when stowed with six months' stores and provisions. Wolf must be considered inferior to them all under these conditions. At the termination of this cruise (October 19th), the ships were ordered to different foreign stations, and the experimental cruising was supposed to be at an end. But Sapphire, Tyne, and Challenger, afterwards met at Plymouth, and they were ordered to make further trial. They had three trials; and the

account received from an officer on board one of the ships, who always took great interest in the experiments, states, that, "upon the whole, it was as equal sailing as could well be."

It is naturally asked by every one, in reference to these experiments, What has been elicited? Has anything new been discovered, relative to the theory of construction? Has any one thing been determined, on which doubts previously existed?—To such questions, we cannot, perhaps, in this instance, give a very satisfactory answer; but we will endeavour to show, from the following observations, which were made at sea, that ship-building may be greatly benefitted by nautical trials, and that the late trials have suggested many hints which it would prove useful to keep sight of in future experiments.

It may be considered as a general maxim, that when experiments are instituted with a view to theoretical inferences, by comparing the performance of different bodies, the bodies prepared for the purpose of experiment should be as similar as possible, except in those particulars, the effect of which it is the object of experiment to determine; for it is obvious, that if the dissimilarity be confined to only one element, unlike results must proceed from that deviation, and may therefore be traced to their true cause. Nor is this the only point to be attended to: the *motive* power should be alike, even to mathematical precision, under all circumstances of trial.

Applying these remarks to the experimental squadron, it must be seen that the effect of any particular element on a ship's sailing qualities is in no way elucidated by the results of the various trials; for no restrictions were imposed on the constructors, as to the proportions of their ships, nor was any systematic regard paid to the application of the moving power. By referring to the Table of Principal Dimensions, &c. (p. 285), it will be seen, that there is great dissimilarity in many of these elements.

It appears that the Challenger and Tyne have nearly the same length and breadth, but that the Sapphire has much greater breadth in proportion to her length than the other frigates. Of the corvettes, it appears that the Acorn and Satellite have exactly the same dimensions; that the Wolf differs but little from these two ships; and that the proportions of

the Columbine differ greatly from the other corvettes,—her breadth being much greater, and her length much less.

As the Acorn and Satellite were built from the same draught,[1] their relative qualifications must depend on circumstances unconnected with their *form*. The quantity and distribution of sail; the arrangement of the ballast, and the general stowage of the hold; the trimming of sails, the skill of the helmsman, &c.,—affect the sailing qualities of vessels so much, that any difference in their behaviour may be ascribed to one or more of these causes; and it is to these points that our attention should have been directed, in the case of the Satellite and Acorn. Such considerations are not less important to excellency in sailing, than the formation of a ship's hull; for the most able ship-builder may be disappointed in his plans, unless the above circumstances concur in favouring his designs. We shall speak, shortly, on the subjects of ballasting and stowage; confining ourselves, for the present, to some cursory remarks on the trimming of sails.

According to Chapman's theory, in his treatise on finding the area of sails for ships of the line, the sails will produce the greatest effect when the yards are so braced as to *bisect* the angle made by the fore and aft line of the ship and the direction of the wind. Experience, however, makes it appear that the angle made by the yards with the direction of the wind may be more *acute* than the remaining angle, provided the sails be kept just full. The celebrated Dr. Robison has given an elegant paper on this subject, under the article "Seamanship," in the Encyclopedia Britannica.

If there be a certain angle at which the yards may be braced with the greatest practical advantage, one would imagine that every yard should be similarly trimmed, if possible: that is, the horizontal section of any sail should be parallel to any horizontal section of all other sails in the ship.

Observations have been taken of the angles at which the several yards were braced, on board some of the experimental

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[1] It is extraordinary that there should be so much difference between the draught of water of the Acorn and Satellite, (page 285) although they were built from the same lines, and were stored and provisioned with every item allowed as the regular "establishment."

ships, during the time of trial. In some cases, the lower yards, the topsail yards, and top-gallant yards, have been found to be in the same plane, or in parallel planes; but, in other instances, they have been known to be braced to different angles. On the *main-mast*, we will say that the lower yard made an angle of 26° with a fore and aft line; the topsail-yard, 31° 15′; and the top-gallant-yard, 39°.[1] And again, the lower and topsail-yards of the fore-mast were braced 1° sharper than those on the main-mast; and the fore-top-gallant-yard 5° sharper than the main-top-gallant-yard. To enumerate these particulars may have the semblance of carrying theoretical considerations too far; but, in truth, it is not so.

We know that the power of the Sails is just equivalent to the resistance opposed to the immersed part of the body, in the direction of its motion; consequently, whenever we vary the mode of applying the *moving* power, the velocity of the vessel undergoes a corresponding alteration. That the trimming of sails anew will cause one ship to pass another, when she has previously been dropping astern, is notoriously true. There is no doubt in the world but we have yet very much to learn, both in the building and manœuvring of vessels; and we must not allow ourselves to be persuaded to the too common idea, that because a ship only behaves well when well managed, that the theory of construction, abstractedly considered, is of less importance. Will it be argued, that because two musicians produce different tones from the same instrument, there is no difference, intrinsically, between a common violin and a Cremona? Does the acknowledged advantages of an expert jockey over an inexperienced rider, render it a matter of indifference as to the real character of a race-horse? Such notions are fallacious in the extreme: nevertheless, they have been urged by many from whom something more logical might be expected. It really is time that everything like mystery and sophistry should be honestly thrown aside; and whoever conceives that he can elucidate any points which have reference to naval science, should approach the subject with a candour calculated to lessen, instead of mul-

[1] The example here given states the position of the Tyne's yards on the 25th of September.

tiply, the uncertainties with which it now abounds. He must acknowledge his ideas to be speculative, if they are so, and invite co-operation on the part of those who are most capable of prosecuting the subject with him. Were we thus to unite in the same common cause, with all the talent and energy we possess, the path is straightforward enough to speak with confidence of what it wouldlead to.

It appears somewhat extraordinary, without a due consideration of the subject, that vessels which differ greatly in the proportion of their principal dimensions, and are very unlike in form, should possess similar properties, and excel on the same points of stability : yet such is the case ; and the fact has been exemplified in the Challenger and Columbine, which were powerful rivals, during the first series of experiments, on all points of sailing. Now the Columbine is a broad vessel compared with her length, but the Challenger is the reverse : she is long compared with her breadth. And further, these two ships are in every respect unlike in the configuration of the hull, both above and below water. They are both weatherly vessels.

To render a ship weatherly, her form, under water, should be calculated to oppose great *lateral* resistance ; which may be effected by giving length, or depth, so as to make the longitudinal section below water of sufficient area : and particular attention should be paid to the area of the greatest transverse section, which should be kept as small as possible, to diminish the *direct* resistance. It is the proportion between these two areas *(cæteris paribus)* that establishes the weatherly property of a ship's bottom : and from this it appears that a naval constructor has great latitude in preparing his designs ; that he is not necessarily confined to any limited proportions, but may accomplish the same end by various means ; and that according to the service for which a ship is wanted, he can regulate his plans without sacrificing any properties beyond what is absolutely requisite.

Now, the power of the wind on the sails of a ship is the reverse of the action of the water on the immersed body ; consequently, a given quantity of sail will have the greatest effect when the yards are so braced that the action of the wind, be-

ing resolved into a fore-and-aft, and also into an athwartship direction, will make the former a maximum, and the latter a minimum. The greater the spread of canvass, the greater the advantages on every point of sailing: indeed, the practice of carrying a heavy press of sail when a ship is embayed on a lee shore—even so far as, at times, to endanger her safety—proves that the greater the impelling power that can be brought upon, and supported by, a ship, the more weatherly she will be. Hence the necessity of a *due* proportion between the moment of sails and the moment of stability. By giving too little sail we throw away the advantages that are within our reach; and by giving too much, we incur evident risk.

It must be acknowledged a difficult problem to determine the quantity and distribution of sail best suited to a ship, unless we are furnished with very correct data, derived from experiment.

Before a naval constructor prepares a design, he procures drawings of a vessel—or of several—of the same class as the ship he is about to construct, the characters of which are known and approved. He acquaints himself with their reputed qualities, calculates their chief elements, and compares computed results with the reports laid before him. Borne out in this manner, by an accordance between theory and practice, he predicts the capabilities of his construction; and his expectations will be realized in proportion to the correctness of the documents with which he is furnished.

It is admitted that the Columbine sailed better during the second cruise than she did before; and, if the observed difference be a matter of importance, a knowledge of the means by which she was improved will, of course, be valuable. The question is, what alterations did she make on the first return of the Experimental Squadron? She is reported to have had the same quantity of stores, provisions, ballast, &c., in both cases; but her main and mizen masts were carried a little further aft, and she had an increase of sail.

If nothing were done to give additional stability, corresponding to this increase of sail, it is evident that her sails were not so well proportioned in the first instance as latterly. Questions of this nature should be gone into as minutely as possible; to

do which, the Columbine's calculated stability and moment of sails should be actually registered in both cases.

While we are on the subject of stability (or that property by which a ship resists lateral inclination) it will not be improper to offer one or two suggestions, from which it may be made to appear that useful hints may be taken from observing a ship's angle of heeling at particular periods.

The writer was at sea in the *Tyne*, and he has reasons for thinking that she never sailed so well as when her lateral inclination was about 12°. During one of the trials, when carrying the same sail as other ships in the squadron, she heeled steadily to 17°; on hauling up her courses, her inclination altered from 17° to 12°, but the diminution of velocity was scarcely perceptible; and, at *less* angles of inclination, the *Tyne's* rate of sailing, compared with the other ships, was inferior to what it was when deflected as far as 12° from the upright. We take a great deal of trouble to discover the best longitudinal trim of a ship, and we register it with some care, knowing that the advantages are, at times, very great; but we never pay attention to the athwartship trim. If we place weights to windward, or use any other method of putting a vessel in a situation more conducive to fast sailing than the position she assumes from her *real* stability, we thus ascertain the best sailing angle for that form of body; and the experiment is not without its advantages.

A practical method here suggests itself of determining the proper stability for a given quantity of sail; and *vice versa*— viz. the quantity of sail that should be applied to a given stability.

When we speak of determining the stability necessary for a given quantity of sail, we mean that moment of stability which is exactly sufficient to counterbalance the effect of the sails at a certain angle. This angle (say 10°) must be settled upon by the intelligence of an experienced seaman, on board the ship on which the experiment is made; or it must be regulated by sailing in company with a vessel whose stability has been approved of, and with which it is proposed to make a comparison of inclination.

Let us first suppose that a ship is *over-masted*, or deficient

in stability. Let such a vessel be allowed to heel as far as her sails will depress her (say 15°), and let the inclination be registered. Take the drawings of the ship in question, and compute her stability at 15°; the result obtained is a moment of stability, which may be given to a new construction at the angle (10°), at which it has been determined she ought to sail under conditions of weather, &c., similar to what were observed at the time of the experiment. The reverse of the proposition is equally easy of application: for if we desire to know the proper *reduction of canvass*, it is only necessary to let the vessel shorten sail until her angle of inclination is the required angle; then, by noting with accuracy the sails actually set, and calculating their moment, we obtain the necessary result for altering the masts and yards.

We will next suppose that a vessel is under-masted; that is, that the vessel is either to have additional sail, or that a new construction is to have less stability. The mode of proceeding is equally simple.

The stability of the vessel at the angle to which she really inclines (say 8°) must be calculated, also her stability at the angle to which it is determined she *ought* to heel, viz., 10°, which is decided upon in the manner already explained: the following proportion will then give the moment of sail required; viz.,

$$\left.\begin{array}{c}\textit{Stability at the}\\ \angle\textit{ to which the}\\ \textit{vessel actually}\\ \textit{inclines }(8^\circ.)\end{array}\right\} : \left\{\begin{array}{c}\textit{Moment of}\\ \textit{sail which}\\ \textit{produces}\\ \textit{this effect.}\end{array}\right\} :: \left\{\begin{array}{c}\textit{Stability}\\ \textit{at the}\\ \textit{required}\\ \angle 10^\circ.\end{array}\right\} : \left\{\begin{array}{c}\textit{Moment}\\ \textit{of sail}\\ \textit{required.}\end{array}\right.$$

But if the quantity of sail were an invariable quantity, and it became advisable to give a new vessel *less* stability, in that case, it would only be necessary to compute the moment of stability at the real angle of the ship's inclination, (8°) and the result obtained would be the required moment at the angle (10°) to which the ship ought to heel.

The chief thing we have to consider respecting a ship's inclination, is the difficulty that sometimes occurs in firing the lee-guns; an evil which ought to be avoided above all others. Naval long guns are so mounted that the limit of their vertical range is 13°, which admits of 4° depression, and

9° elevation. Now it is evident that if a vessel incline beyond 9° she cannot fire a "point-blank" shot. It remains, then, for nautical men—and not for the naval architect—to give some definite statement of the sails that may be set when a vessel opens a steady lee-fire; and this statement should have reference to the greatest quantity of sail,—for it must be acknowledged an imperfection of no small magnitude to find a vessel's lee guns disabled, because a constructor has not given his ship sufficient stability. We may assume that the courses are usually hauled up when a ship goes into action; if so, the remaining quantity of canvass should not have power enough to depress the vessel beyond 9°; but if a constant fire is ever kept up under all sail, a ship must be considered either over-pressed, or deficient in stability, if her deflection from the upright exceed 9°.

The necessity of consulting brevity in a work of this kind compels us to say as little as possible on the several points which there may be occasion to touch upon, in connexion with the subject-matter of the present paper. We shall, therefore, return to the Columbine, which, it has been said, was improved after the first cruise. It is difficult to speak with confidence of any actual improvement in the ships; for the alterations were all made together, and, consequently, their relative performances could be little or no criterion to judge from.

If only one ship had been altered at a time, and each ship, in its altered state, had been brought into competition with the rest, without allowing them a deviation of any kind, it would readily have been detected what actual improvement had taken place. And it so happened that this *was* the case in some measure; for the *Challenger* remained at Spithead between the first and second cruises, and did not, as far as we can learn, undergo any alterations.

Assuming then that she behaved the same on both trials, from going to sea under similar circumstances, her comparative rate of sailing, with others, may fairly be considered a criterion by which the rest can be judged. On these grounds, both the Columbine and Acorn may be said to have actually improved on the second series of experiments, and the Sapphire altered for

the worse. The Tyne was unquestionably better than she was at first; and the Satellite and Wolf much the same as before.

The disposition of a ship's ballast, and the general stowage of the hold, form a question which combines theoretical considerations with experience at sea, as affecting the evolutions of a ship, and more particularly the rolling and pitching.

Before the squadron proceeded on the first experimental cruise, I had an instrument made to exhibit the rolling and pitching motions of a ship at one view. The object of this instrument (independent of its utility in measuring the ship's inclination during the times of trial) was to elucidate two points, viz.,

1. To discover whether the alternate depression of the head and stern was the same; that is, whether there is any difference, in general, between the angles of "pitching" and "'scending."[1]

2. To show how far a ship's lateral inclination is influenced by the motions of pitching and 'scending.

On board the Wolf it was observed that the pitching was always greater than the 'scending. If the pitching did not exceed 2° no descending motion of the stern was observable; or, which is the same thing, the bow of the ship did not rise beyond its original horizontal position. When the pitching was 3°, the 'scending was from 1° to 1° 30′; and, lastly, when the pitching amounted to 7°, the descending of the stern was from 3° to 4°. Generally speaking, the depression of the head has been found to be *twice* that of the stern; and similar observations were made on board the *Tyne*, but the disparity was not quite so great.

Now this is a point which ought to be mentioned; for, although the observation has not proved to be of any immediate benefit, it is the development of a fact which has never before been noticed, and may prove useful in its connexion with other known truths. It may be accounted for from the after-part of a ship having more stability than the fore-part;—from a vessel having an impetus forward, which accelerates the pitching and

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1 "'Scending" is an expression made use of to describe the descending of a vessel's stern below her quiescent water line; or the elevation of the bow above the same line, which is the same thing.

retards the 'scending; and from the sails meeting with a back-action, calculated to oppose 'scending. These remarks, relative to "pitching" and "'scending," are, in a manner, corroborated by a common practice on board most ships; viz., that persons generally sleep with their feet forward; and this custom has, in all probability, taken its rise from a practical knowledge of the fact, that the *head* experiences less descending motion when placed towards the stern.

As regards the second object of the instrument—viz., to show the action of rolling compared simultaneously with the pitching—it was observed, that at the extremes of pitching, there was little or no lateral inclination, but that the heeling was inversely as the depression of the extremities; that is to say, it was greatest when the ship was at her quiescent longitudinal trim, and *evanescent* at the extremes of pitching and 'scending. This is, perhaps, rather a curious than an useful fact. If a ship were to preserve her lateral inclination until she arrived at the extremes of pitching and 'scending, she would be liable to take in seas through her lee-bow and quarter-ports, unless sufficient *sheer* was given to meet the exigencies of the position into which she would be thrown. And small boats must also be similarly formed, or they would ship seas at the extremities, to leeward. But experience does not point out the necessity of more sheer than is consistent with good taste, in giving a light and elegant appearance to a ship's side.

In reference to the stowage of a ship's hold, and the arrangement of the ballast, as a general question, it may be observed, 1. That the more nearly great weights approximate the centre of a ship, (in a longitudinal direction) the less will be their effect on the pitching and 'scending. This appears from the consideration that the greater the distance at which weights are placed from the centre of motion of any system of revolving bodies, the greater will be their inertia, their angular momenta being as the squares of their distances from the axis of rotation. In the ordinary action of rolling, the "winging" of weights will always, on this principle, ease a ship's motion; for if the centre of gravity of the ship remain unaltered by winging ballast (which may or may not be the case) this effect must be produced, because the oscillatory movement of

the vessel becomes more powerful, and is therefore more gradually overcome by the stability, which is a constantly-retarding force. And thus it is that the vibratory motion of a ship is increased in extent, but diminished in quickness, without affecting those properties which involve the equilibrium of floating bodies. It follows, by parity of reasoning, that the more we concentrate weights lengthwise, the less will be the extent of pitching and 'scending: and it is also obvious that, however skilfully a ship may be formed by a naval constructor, she may be made to behave badly at sea, unless every circumstance connected with her internal arrangements and general equipment be thoroughly investigated, to the extent to which they affect her evolutions.

From what has been said respecting the inequality of the angles of pitching and 'scending, it may be asked, *secondly*, whether it would be practicable, and whether any advantages would accrue from making the *angular momenta* of the weights, afore and abaft the centre of gravity, *equal*? We know that if two equal weights revolve on some point in an inflexible rod, the sum of the squares of the distances of those weights will be *least* when the centre of motion is in the middle; or, when *equal*, on opposite sides of the axis of revolution. Now, the angular momentum of a system may be equalized either by attending to the situations of the weights, or by accommodating the centre of rotation to their positions, if their positions be not subject to alteration.

How far this principle may apply to the stowage of ships remains to be investigated, and may, perhaps, form a feature in some future experiment.

Our ignorance on many points which affect the sailing qualities of a ship, has been sufficiently exposed during the recent trials, to show the imperfection of naval science in its present state; and at the same time that this conviction is carried to our minds, we see, with equal clearness, that facts and knowledge derivable from common *experience*, are of vast importance in constructing, masting, and ballasting ships; and all who have had an opportunity of making the observation, must perceive that practical hints continue to suggest themselves in every manœuvre that a ship is capable of.

To make any material advancement in naval construction, and to reduce many things to a system which proper care would accomplish, we should be constantly comparing the actual performance and qualifications of vessels with their predicted properties. This would, exclusively, occupy the time of a plurality of persons; and time so employed, so far from being misappropriated, would lead to the collection of a fund of useful matter not now to be met with, and which the occasional efforts of a single individual can never get together.

Economy in time and labour is an argument too readily admitted in support of many customs; and though it may be expedient, for the general convenience and expedition of business, to use *approximate* rules at times, in mercantile departments,—in preference to correct, but more difficult methods—there can be no good reason for continuing the practice of any custom in the British Navy which is capable of being rendered more perfect. Perhaps the most familiar example that can be cited of an erroneous custom, is the practice of speaking of the size of ships as they are estimated by the "Rule for Tonnage." This rule involves the length and breadth after one invariable manner, for all kinds and forms of ships, and produces a result called "the vessel's tonnage;" and, strange as it may appear, this result does not necessarily point out, or express, any one quality which a ship ought to possess.

The quantity of materials used in building a ship (or the hull alone) is equivalent in weight to the body of water it displaces when floating in a quiescent state; and this is called the *Light Displacement*. When fully equipped with stores and provisions of every denomination, the quantity of water then displaced by a vessel is called her *Load Displacement*. These are two fundamental elements in the construction of ships; and the difference between them being the actual weight of ordnance, ammunition, stores, men, provisions, &c., is the absolute *tonnage* of what is received on board.

Now it may be argued whether a vessel's tonnage should express her capability of carrying weight, or whether it should be the tonnage of water displaced at her extreme lading, which is her "Load Displacement."

If the former, then will all vessels of the same force have the same nominal tonnage, because the weights actually received on board for the purposes of war, including contingencies (being subservient to, and dependent on the artillery), admit of no variation. And if tonnage be intended to signify the Load Displacement, there may, in that case, be a slight variation in ships of the same force, because the constructor is at liberty to use some latitude in the Light Displacement. The following results were calculated a short time prior to the experimental ships going to sea:—

	10-gun Brigs.	18-gun Brigs.	28-gun Ships.	46 guns	60 guns	74 guns	84 guns	120 guns
Light displacement, in tons..	128	212	398	732	1005	1572	1820	2401
Load ditto ditto	258	397	737	1699	2069	2931	3351	4784
Difference, or actual tonnage	130	185	349	967	1064	1369	1531	2383
Builders' tonnage	235	382	499	1077	1477	1741	2250	2616
Error of tonnage	105	197	150	110	413	372	721	335

A very transient inspection of the above table shows that the builder's tonnage is greater than the absolute tonnage for every class of ship in the British Navy. In brigs, carrying 10 and 18 guns, it is about twice as great; in ships of 120 guns there is an excess, but the difference is very small; and in the intermediate classes of ships, the nominal is found to exceed the true tonnage, by *one*, *two*, *three*, and *four* tenths, but not in any regular order.

Now the builders' tonnage is *less* than the Load Displacement for all classes of ships of war. In brigs, carrying 10 and 18 guns, it is nearly the same; but in ships of 120 guns it is very little more than one-half; and in the intermediate classes of ships there are differences, varying from one-tenth to six-tenths, though not in any order of regularity.

From these observations, it appears that we can form no correct idea of what weight a ship of any class actually carries, by knowing her "computed" tonnage; nor does it inform us

either of her light or load displacement. In fact, the builder's tonnage tells us nothing at all, when it has reference to ships of war; and the rule, in its present form, must certainly be regarded as an existing evil, calculated to mislead; and, in all probability, it has caused many serious errors in the construction of men-of-war.

Among the corvettes in the Experimental Squadron, the Columbine is said to have had more tonnage (by 38 tons) than any of the others, her nominal tonnage being 492 tons, while the rest were only 454 (page 285). Now it is more than questionable whether Columbine is not really smaller than the remaining corvettes; for she had less draught of water—the area of her water-line was also less—and her bottom less capacious throughout. But the rule for tonnage involves the square of the breadth, and simply the length; and as the Columbine has more breadth, in proportion to her length, than the rest, her "builder's tonnage" gives a false character of her comparative size. Any person looking at the vessels in question, would not hesitate to pronounce the other corvettes more capacious than the Columbine, without other than ocular proof; and the accounts of the comparative facility with which other ships of this class stowed their six months' stores and provisions, when fitted for the last series of experiments, put it beyond a doubt.

Difference of opinion seems to exist among naval men, as to the necessary capacity for stowage on board ships of war. While some consider that every ship should have the power of carrying six months' stores and provisions under hatches, others maintain that less stowage is sufficient.

The space necessary for containing any number of bodies of known dimensions, depends on rules of mensuration, which there can be no permanent difficulty in applying, with great precision, to the stowage of a ship. The cubical contents of compartments intended for the reception of most of the stores, may be regulated with every exactness; and the entire stowage of every class of ship may, ultimately, be reduced to a very perfect system, by attending to the improvements which experience may, from time to time, suggest.

The sailing qualities of the Columbine excited great curiosity

respecting the peculiarities of her form. The following description is given from casual observation, not having had the opportunity of examining her plans.

Her midship section is sharp, the rising of her floor being about 45°. The body continues to spread in almost a straight line until it reaches about a foot above the water-line, where the curve becomes rather sudden, and forms the "tumble-home" of the topsides. There is not much hull above the surface of the water. Speaking of her form below water, it may be said that she has a full fore-body, and that her after-body is very sharp, possessing an unusual flatness under her buttocks. The vessel is bark-rigged, and steers with a tiller instead of a wheel. Her foremost shrouds are not in a line with the centres of their respective masts, as is frequently the case, but they *rake aft*, which admits of the lower yards being braced up sharper than common. The general appearance of the ship is much approved of; she looks low in the water, and very compact, and behaves better under other circumstances than against a heavy head-sea. Her accommodations are of necessity small, which arises from her being 8 feet shorter than the other corvettes; and her lower port-sills are two inches less height above the deck than in the other 18's, to allow, it is said, of water passing more freely out of the ports, should the vessel "ship a sea."

The rival vessels of the Columbine's class were the Acorn, Satellite, and Wolf; of which the Acorn latterly became a very powerful opponent in bad weather—leaving, indeed, little, if any claim to superiority on the part of the Columbine.

The Acorn and Satellite are already stated to have been built from the same lines, and from the proportions mentioned in the table given in page 285. There is nothing remarkable in their construction; at the same time, there are an elegance and easy curvature in the lines throughout the body, which strike the eye. The extremities under water are rather fine, but not in the extreme; and the midship section has a rising floor, with a straightness continued until it comes within about 18 inches of the water-line, when it assumes a curvature gradually falling into the form of the ship's side, which is nearly upright. The gun-deck of these ships is roomy, and the same may be said

of the lower-deck; indeed, the whole internal arrangement has been greatly admired, both as regards the accommodations for the officers and crew, and the general plan of store-rooms, &c.

The Wolf does not differ, in outward appearance, from the general form of ships: she carries her greatest breadth well forward and well aft; her topsides appear to be almost a perfect plane from the main-breadth line upwards, and they tumble home about 10 degrees; the main-breadth line appears to be rather below water amidships, and (rising towards the extremities) makes a fair curve along the side, passing through the extremity of the wing-transom and a point of about the same height at the second port from forward. The general appearance of the ship is that of boldness and capacity. With the dimensions Captain Hayes has assumed, he has aided the stability, by preserving the vessel's breadth longitudinally, and has improved her weatherly qualities, by giving a form in the vicinity of the water's surface calculated to oppose lee-way, by presenting a perpendicular plane to the water when the ship is at a very frequent angle of inclination; viz., 10°.

In one respect, however, the Wolf is very unlike most of our ships; her ballast being so disposed that the whole,[1] excepting $1\frac{1}{2}$ ton, was placed abaft the mainmast; while the general stowage of stores and provisions resembled that of other vessels of her class. A knowledge of this fact corroborates the assumption that the Wolf's after-body is more than usually full, as she was trimmed to an even keel.

Now the tendency of this fulness in the after-body is to bring the centre of gravity of the ship more aft, or nearer the middle of the ship's length, than it is commonly situated; and this effect, though not without its advantages, is rather to be avoided than desired, for the following reasons.

When a ship tacks, she turns on an axis passing through the centre of gravity, and the resistance opposed to every point is as the square of its distance from the centre of revolution; consequently, the total resistance will be a *minimum* when the sum of the squares of all the distances is least: or, which is the same thing, when the centre of gravity of the ship is in the middle

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[1] 61 Tons.

of her length. So far, then, there is an advantage in bringing the centre of gravity near the middle, lengthwise: but other considerations, important to a ship's general evolutions, more than counterbalance this.

The great weights necessarily placed at the fore extremity of a vessel, (viz., bowsprit, anchors, foremast, &c.) are so serious an evil, that bringing the ship's centre of gravity aft is strongly objectionable, inasmuch as it increases their distance from the centre of revolution; the position of these weights not being subject to alteration. And it is probable that the pitching of the Wolf, which was certainly uneasy, and at times rather violent, may be explained on this principle.

In the next place, it has been found that the immersed part of a ship should always be further forward than abaft, that it may be less opposed, in its direct motion, by the fluid through which it passes; and that it may give better support to the superincumbent weights, of which there is a greater proportion forward than aft, in all ships. The centre of gravity of displacement being therefore before the middle, that of the ship will of necessity be so too, as these two centres must always be in the same vertical line when the vessel floats in a state of equilibrium.

Again: the effect of the rudder is increased in a ratio depending on its distance from the centre of rotation, and the shocks of waves which repeatedly strike the bows of a ship have less effect in turning her from her course, in proportion to the proximity of the part struck to the centre of gravity. These and the above considerations are at variance with adjusting a ship's centre of gravity to the middle of her length; and it is likely that Captain Hayes has himself known some disadvantage from it, if it be truly reported that the Wolf is the "sister-ship" of the last experimental corvette (Champion) built by him, the vessels differing in their after-bodies only,—that of the Wolf being less full than the Champion's. The Wolf generally improved in her sailing when weights were taken forward, which arose, perhaps, from the after-body being raised a little out of the water, and the heavy run abaft thereby lessened.

The position of a ship's centre of gravity lengthwise is a question of easy solution; but to determine its position, in a

vertical sense, requires considerable labour and great care, if obtained by calculation. The readiest method of arriving at this conclusion is by experiment; and it would be useful to ascertain this point practically in the Columbine and Wolf, in which we cannot suppose a very near coincidence, owing to their great dissimilarity of form.

During the first series of trials, the Columbine sailed remarkably upright; and though the Wolf was not represented to be wanting in stability, she certainly inclined much more than the Columbine. In order to compare the stabilities of these ships with accuracy, their centres of gravity should be determined; for we cannot assume them similarly situated, for the reason just given.

In ships of the same class, and bearing a resemblance in form, it is admissible to suppose that their centres of gravity coincide, when we wish to compare their computed stabilities; for the extent to which the stability of a ship is affected, by raising or lowering the centre of gravity, is small compared with the influence which *form* has in establishing that important property.

M. de Romme, in his work *L'Art de la Marine*, remarks—"As to the position of the centre of gravity, no doubt it may vary; but the limits to which it is restricted are very confined, especially in ships of war."

"A recent example in the Scipio, of 74 guns, armed for the first time in 1779, was hardly in the Roads before she was suspected of instability. It was important, in time of war, to clear up doubts on this subject, and to make the necessary experiments to ascertain whether this dangerous defect really existed.

"First, the lower-deck guns were run out on one side, while housed on the other, and the ship heeled 13 inches: the ship's company were then ordered to their quarters at the side on which the guns were out, which increased the inclination to 24 inches. After these experiments, she was tried under different sail in fine weather, both free and close hauled, but was found so crank as to render the use of the lower-deck guns difficult and dangerous. Her instability being thus determined, she was ordered into port to be improved.

"Opinions were divided as to the cause of the defect: some

imagined it to proceed from the form of the hull; others from an ill arrangement in the stowage of the hold. The Chief Engineer was ordered to attend at Rochefort, to direct what measures should be taken to give the Scipio, as well as two other ships, (the Pluto and Hercules, built from the same plan,) the requisite additional stability. The Scipio was unloaded, and then restowed, under the direction of the First Engineer. In her first equipment for sea, she had 80 tons of iron and 100 tons of stone ballast, and, when reloaded, she had 198 tons of iron and 122 tons of stone ballast; and, as her displacement could not be altered, it was necessary to take away 130 tons of water, in order to preserve the same line of floatation. By this means, 136 tons were placed, in the second loading, eight feet lower than in the first; yet, when the ship was completed under this new arrangement, she was found just as deficient as before, inclining 24 inches with the guns out and men at their quarters.

"She was afterwards doubled with light wood, one foot thick, at the extreme breadth, and extending ten feet under water, decreasing to four inches both lengthwise and depthwise."

M. de Romme considers that the instability cannot altogether be ascribed to a want of extreme breadth, as several other 74-gun ships had had the same; but he conceives that it arose from diminishing from the middle, at the plane of floatation, too quickly forward and abaft.

It is certain that the depression of the centre of gravity which amounted to nearly 5 inches, must have contributed to increase the stability, and have occasioned a difference of nearly 3 inches in the greatest inclination; but as experiments, where men are stationed at quarters, are liable to much irregularity, an error of this magnitude may be accounted for from the men running to the side to mark more strongly the defect of a bad ship.

From external appearance, the stabilities of the Wolf and Columbine would probably be found to bear a very different proportion at equal angles of inclination. The stability of a ship increases with her inclination, under certain limits; and it is an important point, that the formation of a body be such as not to make the increase too sudden, as the angle of heeling varies. Attention to this particular will prevent that quick action in rolling which is obviously injurious to the hull, masting, and

rigging of all vessels; and it is certain that a well-constructed body eases a ship's general movements, and renders the question, as to the size of rigging and spread of shrouds, less important.

If, therefore, a vessel of any particular class complain that her rigging be too light, or too heavy, it involves a question dependent on her own peculiar properties, and does not necessarily bear upon other ships of her class. The easiness of a ship's movements, unquestionably affects her durability in a very considerable degree, owing to the endless directions in which she is exposed to strains: hence the permanent strength of a ship's hull, as well as that of the masts and rigging, depend chiefly on the theoretical skill of a constructor. A vessel of small scantling would therefore encounter a storm with more safety than one of stronger build, if injudiciously formed and badly stowed.

In conclusion.—The foregoing remarks are chiefly the substance of a journal kept on board the Wolf and Tyne; and the object of their publication is to show, that when experiments are made to benefit the theory of construction, it is indispensable that the projectors and observers should confer and agree upon measures by which their several opinions and theories may be most fully tried. They are also intended to show that unless the subject be unremittingly prosecuted, by a careful attention to every practical hint, many of the principles of naval architecture must continue to be uncertain in their application; and finally, that there is evidently much to be accomplished, which it would be unreasonable to look for from individual exertion.

Art. XXII.—*Notice of the "Nouvelle Force Maritime et Artillerie. Par H. J. Paixhans. Paris,* 1822. *4to." And of "Expériences faites par la Marine Française, sur une Arme nouvelle. Par H. J. Paixhans. Paris,* 1825. *8vo."*

The art of War has been defined to depend on the single principle of ensuring the advantage of a superiority of force.

In the war of fleets and armies, the concentration necessary to the practical application of this principle, has given rise to the numerous beautiful combinations and manœuvres which form the science of tactics. If we descend from the consideration of fleets and armies, to that of their detail, the ships, battalions, and even *personnel* and *materiel* composing them, the principle will be found to be equally applicable; for as the numerical or physical strength approaches to an equality, the superiority of force will result from the comparative efficiency of the components for the purposes of destruction, or in the means of defence.

The history of the progress of naval architecture, in the various maritime nations, may be taken as an exemplification of this principle. It shows a constant endeavour, on the part of each power, to acquire the advantage of a more perfect concentration of force; that is, to possess the superior class of vessels. Indeed, in whatever manner we may consider naval warfare, whether on its grandest scale, of contending fleets, or in the more frequent occurrence of actions between single ships, it will be found peculiarly to consist in that species of encounter, in which the principle of ensuring a superiority of force will admit of little other application than superior effectiveness.

The progress of the means to attain this object, since the introduction of cannon, has been, first, a gradual increase in the size of the vessels, in order to obtain superiority rather by the number, than by the efficiency of these cannon: but, latterly, that the several classes of vessels appear to have arrived more nearly to those limits which other considerations have drawn to an increase of their dimensions; and that the nature of the advantage to be derived from cannon has been more fully understood: the endeavour has been to obtain the utmost limits of efficient force which each vessel is capable of carrying; or to obtain a maximum of force in a minimum of space.

Experience has determined that the greater the calibre of the shot, the better it is adapted for the purposes of destruction, both with respect to range and momentum; consequently, it becomes evident that the only limit to the weight of metal which may be advantageously used on board a ship, as a projectile, depends on the weight which a man can lift without loss of time, when loading a gun in such average weather as

will admit of actions between ships. But as it is evidently the maximum of *advantage* which should be required, and as large shot necessarily require large and heavy guns, which are opposed to the convenience and quickness of working, to economy of men, and are also extremely detrimental to the good properties of the ship; the maximum will depend on that modification which will ensure the largest possible calibre, with the least weight of gun, consistent with perfect safety from bursting, sufficient steadiness of recoil not to divert the shot from its direction, or to disable the gun by injury to the carriage or tackling, and sufficient length to ensure accuracy of fire, and the other advantages which depend on that dimension.

The theory of projectiles being, from the anomalies of the resistance of the air, inapplicable to practice, the science depends upon experiment for its leading principles. Dr. Hutton, deduced the following results, which refer to the question of the weight and length of the gun, from the experiments undertaken by him in the years 1783-84, and 1785:—"That the range is nearly as the fifth root of the length of the bore. That no difference is caused in the velocity or range by varying the weight of the gun. That the velocity is in a ratio somewhat less than the square root of the length of the bore, but greater than the cube root of the same."

It appears, from these results, that the advantages to be gained by an increase in the length of the gun, are a very small proportionate increase in the range and in the velocity; but neither of these is, beyond a certain degree, of any great importance for the general purposes of naval warfare; for long ranges, with the numerous circumstances which must occur in a ship to render the aim uncertain, must be generally ineffective. On the question of velocity, experience has determined that there is an advantageous limit to the velocity of a shot, to ensure which there has been, from the constant improvement in the quality of powder, a progressive decrease in the proportionate weight of the charge.

It may, therefore, be assumed that the determination of the length of a gun, for naval purposes, must depend on the length of chase which is absolutely necessary for carrying the fire clear of the obstacles offered by the side of the ship, and for training

the gun; and then, that the weight must depend on the charge of powder, and on the steadiness of recoil required.

But it is not alone in the perfection of the *materiel* of naval warfare that the efficiency which will ensure success is to be attained. The strength of a navy depends so completely on the experience of its seamen, that the history of Europe will show that while the navy of England has, from that cause, for centuries been increasing in importance, the navies of the nations and states of the continent have risen and fallen as their commerce (the sole means by which any adequate proportion of their population could become maritime) has flourished or decayed.

The unprecedented naval superiority which England established during the last war, has of course excited her opponents to make every effort to enable them again to compete with her with a chance of success. But it appears to be felt, that circumstances combine in ensuring to Great Britain the general advantage of naval warfare: her commerce, her insular situation, the proximity of every part of her territory to the sea, and the consequent familiarity of every individual of her population with naval affairs, must always ensure the power of her navy. This superiority is so completely felt, that other maritime powers are now turning all their energies to create, by artificial means, some compensation for the absence of this innate naval strength, or to discover some new medium of attack or defence which may render it less irresistible in its effect.

Such are the energies of France, always the most formidable of our rivals, that in spite of the recent utter annihilation of her navy, she is now in possession of a force of 53 line-of-battle ships, and 55 frigates, building or built: and by the budget for 1829, it appears that 6 line-of-battle ships and 8 frigates are to be laid down in the course of that year. And, fully aware of the natural weakness of the resources of her population, in a maritime point of view, she has for some years instituted a large standing naval force, consisting of a certain number of completely-organized crews, adapted either for manning vessels of the line, or twice the number of frigates. The men composing these crews are to be trained as seamen, and kept in constant employment, either in the arsenals, or on board such ships as may be engaged in actual service.

Though such a system as this, appears at the first view to be formidable, it will scarcely in reality be found to be one step in advance towards the removal of the cause of its formation. It requires more time to form seamen than probably any other class of men existing; and it would be difficult, if not impossible, to give any considerable number of men, drawn as those who compose these "*Equipages de Ligne*" are, from every part of France, the habits, experience, and feelings of seamen, with the limited facilities which can be afforded by the marine of any nation in a time of peace, which is necessarily destitute of all the motive and excitement connected with war. But even supposing that, by great exertions and sacrifice, the system answered so far, that at the commencement of the next naval war France might be in possession of a respectable, nay, even a formidable, naval *personnel;* the original cause of weakness would still exist; there would be no adequate nursery, and, consequently, no reserve; therefore, although in a few early encounters we might be met on more equal terms than heretofore, the opposition would weaken as the struggle was prolonged; and a protracted war would find the pre-eminence of the navy of England more proudly and more firmly established than ever.

Among the second class of attempts to make the effect of our natural naval superiority less apparent, may be classed the bomb cannon, proposed by M. Paixhans; under the idea, he says, "that in future the naval power of states may be in proportion to the strength of their whole population, instead of depending, as at present, on that part of it familiarized with maritime affairs."

In the year 1822 M. Paixhans published a work called "Nouvelle Force Maritime." Its title-page declares it to be "An Essay on the Present State of the Means of Naval Warfare; on a new species of Artillery, for Sea Service, of a most destructive nature to the existing classes of Vessels; on the Construction of Sailing Vessels, and of Steam Boats of moderate size, which, being armed with this artillery, will form a much more powerful, and a much less expensive, naval force, than can be obtained under the existing system." This work, which is in quarto, was followed, in 1825, by a small book, in

octavo, containing an account of the experiments which had, in the interim, been undertaken by order of the French government, to ascertain the practical efficiency of M. Paixhans's proposals.

The "Nouvelle Force Maritime" investigates three separate propositions: the first of these supposes the continuation of the present system of ships of war, of various sizes, from line-of-battle ships downwards; and considers how a maximum of force may be obtained in them, combined with unity of calibre, still retaining solid shot as the projectile. The second, under the same suppositions as the last, of ships of various sizes, considers the same question of a maximum of force, and unity of calibre, combined with the adoption of hollow shot. The third proposition involves a complete change in the whole system of naval warfare; the discontinuation of all the large classes of ships, and the adoption of steam vessels, of moderate size, and small sailing vessels, as the only components of maritime force. This proposition involves, according to M. Paixhans's ideas, even a change in the various relations which at present exist between the several maritime powers.

The first division of the work commences by a rapid examination of the various improvements and innovations which have taken place during the last twenty years, in the navies of the several maritime powers, both with respect to the ships and the cannon; but the conclusion is, that gradual progress of this sort, as it will necessarily be nearly simultaneous with all nations, can never be of any other advantage to any of them than in preserving them in their present relative station; and, therefore, "the only means which can wrest the power from the possessor of it, must be such a change of system as will render useless the means by which that power was obtained, and is sustained."

M. Paixhans notices the various discrepancies which still exist with regard to naval artillery; the variety of guns and of calibres used to produce the same destructive effect; the little apparent regularity displayed in the application of their power; and the want of system which is observable in the various proportions between the gun, the charge, and the projectile. He considers that as long as solid projectiles are used, cannon should

be the only weapon; the objection to carronades being the violence of their recoil. But that, "although solid shot may be applicable for making breaches in the stone walls of a rampart, hollow shot, filled with powder and other combustible matter, are far more adapted to rend and set fire to defences of wood, impregnated with tar; and, especially in time of action, replete with every species of inflammable substance, and crowded with combatants."

M. Paixhans considers that, from the innovations by which the smaller calibres have been gradually replaced by larger, and the number of different calibres diminished, there has been a constant tendency to approach a maximum of force; which he defines to consist in the greatest possible increase of destructive effect, combined with the greatest possible simplification of the means; which will be attained, "*when the calibre of the largest sized cannon on the principal battery of ships of the line, is adopted as the sole calibre used for the artillery of ships of war.*"

M. Paixhans then proceeds to the determination of the maximum calibre, from a consideration of the various calibres in use among the principal maritime nations, and he adopts the French 36-pounder as the most efficient under all circumstances, as a solid projectile.

With regard to the proper proportion of the charge of powder, he says, "the question should be, not what quantity will produce the greatest effect? but, what quantity will produce the effect most conducive to the object in view? which is the destruction of the planking and timber of the adverse ship; not by shot passing with such velocity that the elastic force of the wood will nearly close the aperture it has made, but by shot rending and tearing their passage through the side, and scattering around dangerous and destructive splinters;" and that, at least, all that can be urged is, that the quantity of powder must be in proportion to the effect to be produced, more than to the weight of the projectile; in fact, that practice evidently shows this, "as a 36-pounder shot is fired from a cannon with a charge of twelve pounds of powder, and from a carronade with only four."

He then examines the relation which exists between the weight

of the shot and that of the gun, in the most approved pieces of artillery; and from the experience thus collected, he proposes,

"1. That the 36-pounder guns, weighing 7190 pounds, requiring a charge of twelve pounds; shall continue to be used on the lower decks of line-of-battle ships.

"2. That 36-pounder guns of the same weight as the present 24-pounders, that is, 5116 pounds, and requiring a charge of from seven to eight pounds of powder; shall be used instead of the present 24-pounder guns, for the middle decks of line-of-battle ships, and the main decks of large frigates.

"3. That 36-pounder guns of a mean weight between the weights of the present 18 and 12-pounder guns, and requiring a charge of from five to six pounds, shall be used instead of the present 18 and 12-pounder guns, for the upper decks of line-of-battle ships, and the main decks of small frigates, and other small vessels.

"4. That the present 36-pounder carronades, weighing 2500 pounds, and requiring four pounds of powder, shall be used for the quarter-deck and forecastle, in line-of-battle ships and frigates; and for the main-deck of corvettes, &c."

M. Paixhans considers that the objection which would be made to these propositions, might arise from comparing these new guns with carronades, and considering, that though carronades combine large calibre with lightness, it is only because, being used in the upper parts of ships, where great length of chase is not required to clear the side, they may be short, and the weight of metal saved by the diminution of length, will ensure sufficient thickness round the charge; but that artillery destined to be placed between decks being necessarily long, to clear the obstacles rising from the thickness of the sides, must therefore be heavy.

To avoid this difficulty, M. Paixhans proposes that the trunnions in his new guns shall be placed much nearer the breach than in the old ones, and that still to preserve the proper "preponderance;"[1] the swell of the muzzle shall be dis-

[1] The weight which if placed at the muzzle of a piece of artillery, will put it in equilibrium round the axis of its trunnions. The "preponderance," in the French ship artillery, is $\frac{1}{20}$ the weight of the gun, for the short 36's, and for the 36, 30, 24, and 18-pounder carronades; and $\frac{1}{18}$ for the short 24-pounders.

continued, and all useless metal studiously avoided, while the breach and button may be made weighty. With this same view, he also proposes, that the bore shall have a chamber for the reception of the charge, and shall have a slight evasement at the muzzle; by all which means, and from the consideration of the reduced charge of powder, which will admit of less thickness of metal, he considers that his guns will have the advantage of the increase of calibre, and have, at the same time, an equal length of chase with the guns which they are intended to replace. With regard to the recoil, he observes, that in consequence of the increased weight of the projectile, it will be more considerable than in the old guns, but that it will not be equal to theirs when fired with more than one shot.

M. Paixhans enters into an examination of the effect of what he calls the extraordinary means of naval warfare, under which head he classes all those implements and means of destruction, which are not usually resorted to, such as fireships, torpedoes, floating batteries, steam boats, and a numerous list of projectiles. He endeavours to prove, by citing instances of failure, that but few of these are entitled to much consideration, and he concludes, that steam navigation, and hollow projectiles, are the only exceptions worthy of particular attention. He says, "the navy of every nation is still armed with the same massive shot to destroy a fragile and combustible structure of wood, that is used to batter down fortifications of stone: the largest of these is a 36-pounder, and it is evident that such projectiles can do but small injury to the *materiel* of an enemy, since a ship may be struck by some hundreds of them without being destroyed. In the attack by Lord Exmouth on Algiers, in 1816, the Impregnable was struck by 268 shot, fifty of which were beneath the line of the lower deck, and three shot of 68 pounds were six feet below the line of floatation, and yet this ship returned in safety to Gibraltar. What would have been her fate had she been struck with 268 hollow shot? In fact, the effect of solid shot cannot be considerable, even against the *personnel* of a navy, since, in the twelve principal naval actions of the wars of the Revolution, the English had but 1720 men killed; in the first American war, only 1243; and in the seven years' war, but 1512; that is, a loss of only 4475 men in the actions of three wars."

M. Paixhans then says, that though the destructive effect of hollow projectiles charged with powder has been long known their general adoption has been rendered impossible, from the inefficiency of the artillery, which alone was appropriated for using them, in all the essentials of correctness and extent of range, certainty of effect, moderate recoil, and the preservation of the carriage; above all, from its utter unfitness for the general exigencies of the naval service. Even with all these disadvantages operating against them, M. Paixhans says, that shells have always been considered the most formidable weapon that could be used against shipping; if so, how much more effective must they be, he argues, when, instead of being discharged into the air to fall from thence almost at a hazard, they possess all the advantages of accuracy which can be given them, by assimilating their discharge to that of cannon balls; their mass being, at the same time, equal to five or six of these.

M. Paixhans then quotes numerous instances of the destructive effects of shells when used against shipping, and gives an account of a vast number of experiments which have been from time to time undertaken to prove their efficiency, and to render it more generally available. He quotes the opinions of many men of the greatest experience and of the highest talents, as to the expediency of endeavouring to extend the range of their utility; among whom we find Vauban, Cormontagne, Gribeauval, Bousmard, Scharnhorst, Willantrois, and Napoleon. M. Paixhans gives several letters written by Napoleon on this subject; the following are extracts from two of them, the first, in October 1810, was written to the minister of war:—"Je vous charge de faire faire un projet pour les pièces propres à tirer des bombes, ou obus de huit pouces, - - - - ces pièces d'un gros calibre sont très utiles contre les vaisseaux." And again, in August, 1811:—"Je désire que vous me fassiez couler comme essai, à la fonderie de Douai, un canon que puisse tirer des obus de huit pouces. Faites faire également quelques boulets du calibre de 78, pour tirer avec ces nouvelles pièces, et voir l'effect que cela produirait."

This cannon, which M. Paixhans says, is still at Douai, was intended as a defence for a coast battery: it weighs 8500 pounds. M. Paixhans says, this weight was not rendered ne-

cessary on account of the shell, about a 45-pounder, which it was intended to discharge from it, but by the 78-pound shot.

The effect of hollow shot being admitted, M. Paixhans then shows how greatly the destructive effect of these projectiles may be increased by an increase of their size, which, by enabling them to contain a much larger proportion of ammunition, will make their explosion when lodged in the side of an enemy's vessel more decisive. He then proceeds to prove the possibility of using this increased calibre with horizontal fire, by the following observations :—

1st. "The calibre[1] of projectiles, that is, the weight of the sphere supposed solid, is in proportion to the cube of their diameters; consequently, a great increase of calibre may be obtained by a comparatively small increase of diameter; thus, by doubling the diameter of a 24-pounder hollow shot, containing only one pound of powder we obtain a shell of the calibre of 200, and containing eight pounds of powder.

2dly. "Since the thickness of the side of a ship will continue the same as at present, the increase in the calibre of a ship-gun, need not be accompanied by any increase in the length; and therefore the weight of a gun may increase in a much less proportion than its calibre.

3dly. "The largest hollow projectiles which are at present used with horizontal fire, are shells of eight inches in diameter, that is, a calibre of 80; and the artillery from which these are discharged, does not weigh more than 1150 pounds, the charge must necessarily, therefore, be very small, and, in fact, the range is not equal to that of a 4-pounder gun. But the Spaniards have lately made howitzers of the same calibre, weighing 2400 pounds, which by admitting the use of larger charges of powder, give their projectiles a range equal to that of large cannon. It is therefore evident, that with the charge of powder, and length of gun, which might be obtained by the use of a weight of from 5000 to 7500 pounds, that is, from four to six times that of the French howitzer, and from two to three times that of the Spanish, and which weight is that

[1] The term "calibre," in English, refers to the diameter of the bore of the gun; we shall, however, in translation, use it according to the definition M. Paixhans has here given of it.

commonly used for ship artillery, shells of a larger calibre than 80 might be effectually used.

"It results from these observations, that by a proper distribution of the same quantity of metal which is at present used for ship artillery, other artillery may be formed, of sufficient calibre for the shells mentioned, of sufficient strength to resist the action of the charge of powder necessary, of sufficient length to be clear of the sides of the ship, and of sufficient weight to resist the violence of recoil; for the large-sized cannon offer sufficient resistance to this action, even when discharged with three, four, and five solid shot, and a proportionate quantity of powder: now there is as much solidity in two shot of 36 pounds, as there would be in a shell of the calibre of 120."

M. Paixhans then assumes the weights 4200, 5100, and 7200 pounds, that is, the weights of the French 18, 24, and 36-pounder guns, and as he has before decided that the destructiveness of a projectile is in proportion to its calibre, the question becomes, what sized shells can be discharged from cannon of these respective weights? The limits by which it is confined are, the length, dependent on the situation of the gun; the strength, dependent on the calibre of the projectile, and the charge of powder; and the recoil, dependent on the weight. M. Paixhans says, that as the new guns are to replace the old, the length of chase may be retained; and as the thickness of metal need only increase in proportion to the cube root of the diameter of the bore, and as proportionately less strength is required to discharge hollow, than is required for solid shot, sufficient strength may be easily attained; therefore, the only limit to the size of the projectile will be the ensuring sufficient inertia for the recoil.

The weight of the gun in proportion to that of the shot is determined from the results of a table containing these proportions for most of the artillery at present in use; the deduction is, that from 70 to 100 times the weight of the projectile, would be found to be sufficient; and that, therefore, with artillery of the weights of the 18, 24, 36, and 48-pounders at present in use, projectiles of the calibre of 90, 110, 150, and 250 might be discharged; but that for the sake of unity of

calibre, and also for the advantage and convenience of not exceeding the weight of the largest projectile at present in use on board ships, the calibre of the hollow shot shall be limited to 48. M. Paixhans then proposes,

1. "That the present 36-pounder carronades, weighing 2500 pounds, and also the cannon of twelve pounds, shall be replaced by carronades, adapted to discharging shells of the calibre of 48, and weighing 35 pounds; which carronades would, therefore, weigh about 72 times their projectile.

2. "That the 18-pounder guns, weighing 4200 pounds, be replaced by cannon of the same weight, but of the calibre of 48. This gun would weigh 120 times its projectile.

3. "That the 24-pounder gun, weighing 5100 pounds, be replaced by cannon of the same weight, but of the calibre of 48. This gun would weigh 145 times its projectile.

4. "That the present 36-pounder gun be rebored to the calibre of 48; this gun will then weigh 201 times its projectile."

Thus M. Paixhans extends the same principle of unity of calibre, combined with increase of force, to his system of hollow shot. But as the reason of fixing on the calibre of 48 was for the sake of unity of calibre, and not because that was the limit of the advantages which might be derived from the weight of the present heavy artillery, he adds the two following propositions:—

1. "That bomb cannon of the weight of 7200 pounds, that of the present 36-pounder guns, and of the calibre of 80, be made. The shell for these guns, when charged, will weigh 55 pounds, and be 8 inches in diameter. The proportion of the gun to the projectile will be 130.

2. "That bomb cannon of the weight of 10,800 pounds, that of the 48-pounder guns, made in 1812, and of the calibre of 200, be made. The shell for these guns will be eleven inches in diameter. The proportion of the gun to the projectile will be 80."

M. Paixhans then, in pursuance of the same principle to which he adheres throughout his work, deduces the thicknesses and proportions of the several parts of his cannon, from the experience of what has been found to succeed in actual practice,

as exemplified in carronades, mortars, howitzers, and willantrois;[1] and also on the opinions of Scharnhorst, Gribeauval, and other writers.

M. Paixhans then enters into the detail of the projectiles, or shells; these he determines should be of $\frac{2}{3}$ the weight of the solid sphere of the same diameter; and, for the sake of correctness of fire, should be concentric, that is of a parallel thickness of metal. He recommends the use of a metal fusee, screwed into the shell: and that the bomb itself be filled with the following proportions:—$\frac{9}{12}$ of the best gunpowder, $\frac{2}{12}$ of incendiary composition, and $\frac{1}{12}$ of a composition to create smoke, when the shell bursts on board an enemy's vessel.

The next thing M. Paixhans considers is the charge of powder calculated to produce the most desirable effect with this species of projectile. This effect he defines to be,

1. "That it shall be sufficient to give ranges equal to those of the larger cannon at present used on board ships, and this without requiring too great an elevation.

2 "That it shall be only sufficient to force the shell through the side of the enemy, with such velocity, that the largeness of the mass of the shell may have its full effect in tearing and rending itself a passage, and making destructive splinters.

3. "That it shall not cause too great velocity, but only enough to ensure the shell's exploding, either in the side of the ship, or on board; to give full effect to the composition with which it is charged."

From a table of the proportionate charges of numerous pieces of artillery, M. Paixhans finds that they vary from $\frac{1}{24}$ to $\frac{8}{24}$ the weight of the projectile; and from a selection from among these, he proposes the following charges:—

1. "For the carronade, of the calibre of 48, and of the weight of the present 36-pounder carronade, a charge of $3\frac{1}{2}$ pounds of powder; this will be $\frac{1}{12}$ of the weight of the hollow shot when filled.

2. "For the 48-pounder gun, of the weight of the present

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[1] A species of mortar, named after its inventor. The mortar in St. James's Park, which was used at Cadiz, is a Willantrois.

18-pounders, a charge of $4\frac{1}{2}$ pounds; this will be $\frac{1}{8}$ of the weight of the projectile.

3. "For the 48-pounder gun, of the weight of the 24-pounder, a charge of 6 pounds; this will be $\frac{1}{8}$ the weight of the projectile.

4. "For the 36-pounder gun, bored to the calibre of 48, a charge of from 6 to 8 pounds of powder.

5. "For the 80-pounder bomb cannon, of the weight of a 36-pounder, a charge of from 8 to 9 pounds; this will be $\frac{1}{7}$ the weight of the projectile.

6. "For the 150 or 200-pounder bomb cannon, a charge of 10, 12, or even 15 pounds of powder."

For all these guns, with the exception of those of the larger calibre, M. Paixhans proposes that carriages similar to those which are at present in use be adopted, as the weights of the guns will be the same, and there will be no alteration in their form which can affect the carriage. For the larger bomb cannon some modifications in the carriage are proposed, with the intention of lessening the violence of the recoil, and facilitating the loading of the piece. The body of the new carriage is to be similar in shape to that of the present carriage, but without the trucks; so that the recoil will be opposed by the friction of the carriage on the deck, or on a platform laid for it. But as this friction would also increase the difficulty of working the gun, two wheels are placed one on each side, near the breast of the carriage, in such a manner, that they may be made to bear on the deck by raising the rear of the carriage with a lever; this lever has a small wheel in its lower extremity, and is so contrived, that the carriage will, when the lever is under its rear, be supported on the three wheels mentioned, which are intended to facilitate its being run in or out. There is also to be a directing bar, connected to the side of the ship by a fighting-bolt, and of sufficient length to admit of the gun's being run in to be loaded. The bed and transom of the gun-carriage will be scored over this bar. In order to facilitate the training the gun in a fore-and-aft direction, the midship end of this directing bar is to have a small wheel in its lower surface lying in that direction. Also, to obviate the difficulty of loading these guns with such a weight as the large shells must

be, it is proposed to have at the side end of the directing bar, a vertical rack, with a pinion placed horizontally; at the upper extremity of the rack, a vessel or saucer is placed to receive the shell, which may then, by turning a handle connected with the pinion, be raised to the height of the muzzle of the gun.

M. Paixhans having thus proposed for the present classes of ships, first under the system of solid, and then under that of hollow shot, an armament which he considers unites the maximum of force with the greatest possible simplification of the means; and having also shown the possibility of a far greater extension of the destructive powers of the system of hollow projectiles, by the increase of their calibre, next proceeds to the third division of his work.

This division consists of an inquiry into the possible or probable changes in naval warfare, which may arise from the introduction of bomb cannon; and also into the means by which the advantages which are to be derived from them, by the increase in their calibre, may be made the most available to practice. M. Paixhans pursues this inquiry on the principle that with the present system of solid projectiles, a large vessel has little or nothing to dread from the attack of a smaller one; but, that with the new system, from the incomparably greater destructive power of the weapon used, the safety of the largest ship might be endangered by the smallest. This fact, he argues, must operate a vast change in the whole system of naval warfare, and will materially alter the existing relations between the various maritime powers; for, since the comparative force of ships would no longer depend on their relative size, the expenditure of men and money necessary to equip a large ship would no longer, as heretofore, purchase her immunity from all danger except such as must arise from a force opposed to her at an equal, or superior, expenditure; therefore such costly machines would necessarily cease to exist, as no nation would equip a force which might be opposed to, and even destroyed by, one of comparatively trifling expense; and thus, consequently, the great obstacle to acquiring and maintaining a large naval force, which consists in the necessity of possessing an experienced and numerous *personnel*, would be wholly removed.

It naturally arises, M. Paixhans concludes, from the fore-

oing considerations, that the present classes of ships might be advantageously superseded by others of less expense, and more adapted for the efficient use of bomb cannon of large calibre. M. Paixhans argues, that although, from the great destructive force of the individual weapon used, the smallest vessels, armed with them, might, in many cases, be quite sufficient to compromise the safety of the largest vessels, armed on the whole system; yet as there are many circumstances under which such vessels would not be effective, it becomes necessary to determine in what the limits which should regulate the sizes of those which might most advantageously be adopted, should consist.

M. Paixhans says, that the maximum limit does not depend on the *number* of bomb cannon necessary to oppose a line-of-battle ship, armed as at present, since this would be very much dependent on circumstances; but that the limit must evidently arise from the consideration that a vessel of the new class, should not be inferior to one of the old, in those qualities which contribute to the efficiency of the force she is destined to carry; thus the vessel of the new class should possess equal speed with the ships to which she will be opposed, under all circumstances of wind and sea; and she should also possess, at the least, an equal power of using her new "arm" effectively in heavy weather. Neither of these conditions involve, M. Paixhans considers, the necessity of having a very large vessel, especially as he concludes a sufficient number of the bomb-cannons, to meet every possible contingency, may be carried on a single battery; consequently the new class of ships may be built solely with a view to ensuring velocity, and such stability that the battery may be of a sufficient and considerable height from the water.

In the former part of this work M. Paixhans came to the conclusion that steam navigation was peculiarly adapted to combine with the new system of hollow projectiles; and in this division of the work he again reverts to that conclusion; he points out the advantages that steam boats would possess, from their progress being totally independent of the wind; from the facilities which this circumstance also affords to the diminution of their draught of water; from their navigation not necessarily requiring any great knowledge of seamanship; from the com-

paratively small number of hands required to form their crews; and also from the comparatively small risk they would run, in a military point of view, as size not being necessary to ensure velocity, they need not be larger than is required for the effective use of the force they would be intended to carry. "There is also," he says, "another advantage peculiar to them, arising from the power which their mechanism affords of turning the paddle-wheels in either direction, by which they would be enabled to avoid presenting a larger mark for their enemy than would be afforded by their extremities." M. Paixhans does not however consider steam navigation has yet (1822) arrived at sufficient perfection to warrant the sole use of steam boats for the new classes of ships. He, therefore, proposes both sailing vessels and steam boats; and that the principal ship in the new system "shall be a frigate, of a middling size, armed solely with bomb cannon," principally of the calibre of 80; but each vessel may also carry several of the largest calibre.

The steam boats are to be of various sizes; the smallest of sufficient dimension to carry one bomb cannon of the calibre of 200, to be fired from each extremity of the vessel, and to be a sufficiently good sea-boat to use these cannon effectively in an ordinary state of the weather: but these small boats are to be considered more as forming a local force for the defence of harbours and coasts, and are not intended for distant enterprise. The other steam boats, of larger dimensions, are to be constructed to carry several bomb cannon, to be fired from each extremity, and to have such qualities as will enable them to be, in some degree, sea-going vessels. All the steam boats are proposed to be built and fitted to obtain the greatest possible velocity which the most improved state of steam navigation will admit of, as the principal advantages which may be derived from them will be the result of their being able, in many cases of calms, or adverse winds, to attack sailing vessels almost with impunity. The reason M. Paixhans only proposes their being armed at the bow and stern is, to take advantage of the peculiarity which, it has been already mentioned, they possess, of never offering, either in attack or retreat, a larger mark to their opponent's shot than is afforded by their transverse section.

M. Paixhans also proposes floating batteries, to be armed solely with bomb cannon of the largest calibre; these batteries are intended to be used for the defence of harbours, roadsteads, &c.; and, in very many cases, to supersede the necessity of coast fortification. These batteries, also, are proposed only to have a single range of ports.

As all these classes of vessels, from the smallest, are to compete even with the largest opponent, and as their upper-decks must be completely commanded by the higher batteries of the present two and three deckers, M. Paixhans proposes that this deck shall be protected either by iron, or by some means of sufficient strength, that the shot, which will necessarily only strike its surface at a very small angle, may not be able to penetrate, and will, therefore, ricochet from it.

M. Paixhans enters into some further detail respecting the extension of the application of defensive armour for ships; he considers the plan sufficiently practicable to authorize both inquiry and experiment to be made in further consideration of it. He proposes the application of metallic defences to the exterior of his floating batteries, and to the bows and sterns of his steam boats.

M. Paixhans concludes by recommending a series of experiments to be made, on a scale of actual service; that is, that cannon of the various calibre proposed, should be cast, and the effects of their discharge, with shot, shells, and grape, carefully observed, both against shipping and fortifications; and then, should the results of these experiments be satisfactory, he proposes that a corvette and a steam boat should be built, and fitted with the bomb cannon, in order that they may be put to the test of actual service. It appears from the octavo pamphlet, which was published in 1825, that the first division of this series of experiments has been actually undertaken, by order of the French government. This pamphlet contains a summary of the principal points of which an account has been given in the "*Force Maritime.*" It also gives the detail of the above-mentioned experiments, and extracts from the reports made on them.

The experiments were made with cannon of the calibre of 80, 36, and 24; and an old 80-gun ship was chosen to serve as the subject of the experiment; every precaution being pre-

viously taken to prevent her either taking fire, or being sunk; a number of shells were then successively discharged at her from various distances, and with various charges of powder; after each discharge she was examined, and the effect of the entry and explosion of the bomb carefully detailed, both with respect to the damage done to the vessel, and to the number of effigies of seamen which were placed in her.

The following is an extract from the report of the commission, which consisted of sixteen officers of the navy, artillery, and *Genie Maritime.*

"M. Paixhans has proposed, 1st, to discharge shells at the same angles at which solid shot alone have hitherto been usually fired. In this he has completely succeeded. 2dly, to produce great effect in a vessel struck by these shells. The effect of these projectiles is evidently so terrible that we suppose one or two of them bursting on a deck, would cause such confusion and destruction, as would render the possibility of the continuation of the defence questionable. 3dly, to produce, by the explosion of the shell in the sides of the vessel, such damage that would, if it took place near the water, compromise the safety of the vessel. There can be no doubt on this head, as may be proved by the effect produced in one of the experiments, which was such, that if it had taken place near the water, would have been irremediable."

Experiments were also made to ascertain the comparative ranges of the new and the old guns, and of the former with both solid and hollow shot. The following table contains the results of these experiments. The solid shot, of the calibre of 80, weighed 83 pounds; and the hollow from 56 to 58. The solid shot of 36, weighed from 38 to 39; and the hollow shot of that calibre, from 26 to 27 pounds.

We give, in conclusion, the following table of the principal dimensions of M. Paixhans's cannon. (See Figs. 38 and 39). Fig. 38 shows the form of the proposed guns; and fig. 39 shows the chamber, with the charge, shell, and wood bottom.

Angle of Elevation.	Bomb-Cannon of 80.			Present Cannon of 36.		
	Charge.	Mean Ranges in Toises.		Charge.	Mean Ranges in Toises.	
		Solid.	Hollow.		Solid.	Hollow.
	lbs. oz.			lbs. oz.		
3	10 .. 0	849	844	7 .. 3	826	799
5	10 .. 0	993	906	7 .. 3	1134	901
8	12 .. 6	1064	1107	9 .. 0	1102	1100
10	12 .. 6	1166	1198	9 .. 0	1291	1175
16	16 .. 8	1692	1692	12 .. 0	1774	1563
		5764	5747		6127	5538

These mean ranges were determined from the average of six discharges with the same charge of powder, at each angle of elevation.

We shall now offer a few observations on the alteration proposed by M. Paixhans. The principle by which he has been guided is—assuming a certain weight of projectile; he determines, from the experience afforded by the comparison of a large number of pieces of artillery, the smallest proportionate weight of gun which will possess sufficient inertia to ensure a moderate recoil in proportion to the charge of powder used; on this consideration he determines, that with cannon of the same weight as those at present used on board the French ships, larger and heavier projectiles may be discharged, without any disadvantageous increase in the recoil of the gun. This conclusion would be perfectly correct if he could, at the same time, retain the adjustment of the weights in his gun, similar to that of the weights in the gun it is to replace: but to enable him to preserve the same length of chase, and to increase the strength of the gun at the part about the charge, in proportion to the increased charge, he is obliged to make very considerable alterations in their adjustment.

He evidently founds the alterations which he proposes in the proportion of the weights of the parts of his gun, on the principle that it is sufficient to preserve the same preponderance, without regard to the manner in which it is acquired. In the

guns he proposes, the proportionate length of the part in the rear of the trunnions is very much diminished, while its weight is increased; and that of the part in front of the trunnions is proportionately diminished; so that the distance of the centre of gravity of M. Paixhans's gun, in rear of the trunnions, will be much less than in the old gun; though, from the difference in the adjustment of the weights, both guns will preserve the same preponderance.

Now, by the force of the re-action of the charge, a gun, when fired, not only acquires a motion in the direction of its length, which is opposed by its inertia, but also, as the motion in that direction is checked, an angular motion round its trunnions, usually called kicking, takes place: this motion is opposed by the moment of inertia of the gun, estimated from the axis of its rotation, the centre of the trunnions; that is, the weight of the gun multiplied into the square of the distance of its centre of gravity in the rear of the centre of the trunnions.

Now, if we suppose the gun to be in equilibrium round the axis of the trunnion, the weight, which, if placed at the centre of gravity of the gun, would give it the same preponderance as the old gun, will vary inversely as the distance of that centre of gravity in the rear of the trunnions. But the weight, which, if placed at the centre of gravity, would preserve the same moment of inertia which existed before the alteration, will vary inversely as the square of that distance: consequently, that part of the motion of recoil which is usually called kicking, will be less opposed, and therefore more violent, in M. Paixhans's gun than in the present gun of the same weight; even under the supposition that the steady recoil on the breeching is the same in both guns: but M. Paixhans, as we have before said, admits that this action will be more violent in his gun than in the present gun, in consequence of the greater weight of the projectile. This will, of course, further increase the violence of the kicking. Now, this motion is, particularly for ship guns, extremely injurious; for, after a few rounds, when the heat of the gun has had the effect of increasing the proportionate strength of the charge of powder, its violence is frequently sufficiently great, especially in connexion with the motion of the ship, to upset, and consequently, for a time, to disable many

of the guns. One of the first considerations, therefore, in all alterations in ship artillery, should be that of assuring the greatest possible proportionate angular inertia, estimated in the rear of the trunnions.

The experiments which were made with M. Paixhans's guns only determined the destructive effect of the projectile; in consequence of which, sufficient time was allowed to elapse between every discharge, while this was being ascertained, for the gun to cool; and therefore no conclusion could be drawn as to its efficiency with respect to recoil, during the rapid firing in actual combat, within point blank range.

Though there can be no doubt that the system of attaining a maximum, by the adoption of the unity of calibre, would be attended with some practical conveniences, it remains to be determined whether the foregoing considerations may not render further modifications necessary to avoid the inconveniencies which would attend the extent of alteration M. Paixhans proposes to make in ship artillery, in order to obtain this advantage. However, these objections only attach to those divisions of M. Paixhans's proposal which relate to the existing classes of ships. The third division proposes the discontinuance of those classes, and the introduction of others, to be built purposely for the reception of bomb-cannon; in these, the ship may be completely subordinate to the weapon it is to carry; therefore the ordnance for all these classes of ships may be rendered as perfect and efficient in every respect as the improvement of modern art can make them; and to these classes, we conceive, M. Paixhans should have restricted his proposals.

The question of the danger attendant on the use of hollow shot is one which can scarcely be decided but by experience; we have before us a "Memoir on the Use of Shells, Hot Shot, and Carcass Shells, from Ship Artillery, by Captain Hastings, of the Greek steam vessel of war, Karteria," from which we shall quote one or two passages, as giving the opinion of an officer of some experience in the use of these projectiles. "An objection I have frequently heard made to the use of shells on board a ship is, the danger of having a quantity of loaded shells continually on board; to me the loaded shells have always appeared less dangerous than powder, in cartridge, or in any other

form: I placed each loaded shell in a box, these were stowed in the shell-room in rows, retained by stanchions and shifting battens; and on the lid of each box was written the length of the fusee and the nature of the shell; each shell was handed up in its box, and only taken out of it at the moment of being placed in the gun. - - - - I have fired about eighteen thousand shells from this ship, and have never had the slightest accident from explosion; the guns have never broke a breeching, drawn a bolt, or injured a carriage."

One of the obstacles to the perfection of practical gunnery arises from the rotatory motion which a shot acquires, either by its friction against the sides of the piece from which it is discharged, or by some imperfection in its manufacture. The axis of this motion not being coincident with the line of motion of the projectile, causes an inequality in the resistance the air opposes to the parts of its surface, that will of course act as a constant force in altering the direction of its motion. This inconvenience is remedied in small arms by the use of rifled barrels. Attempts have frequently been made to introduce the same principle in artillery, but with very partial success. In a paper by Lieutenant Colonel Miller, in the Philosophical Transactions for 1827, Part I., is an account of an invention of his, which certainly, in principle, completely removes the above-mentioned difficulty, and from the experiments detailed in the same paper, appears capable of being perfected in all the essentials for practical success.

Colonel Miller having observed that the resistance of the air on slight imperfections on the surfaces of shot, produced considerable effect on the direction of their motion, concluded, that the rotatory motion of a rifle ball, was not so much the result of the motion it acquired in forcing its passage along the spiral grooves in the bore of the barrel, as of the continued action of the air on the spiral ridges raised on the elongated ball. By firing shot of a cylindrical shape with spiral grooves on their surface, from a cannon with a plane bore, he found his conclusions were correct; and that these shot acquired a rotatory motion round the axis of the cylinder; this motion was further preserved by distributing the weight of the

cylinder, so as to prevent any alteration in the position of its axis, from the line of motion.

This alteration in the form of the projectile, from a sphere to a cylinder, may be advantageously adopted, especially in long ranges, where precision is required; and, therefore, in all the smaller classes of vessels, which could, of course, only compete with the larger ones under such circumstances. Solid shot of this shape, of increased weight, and consequently with an increased momentum, might be fired from the bore of all the present artillery, having sufficient inertia to withstand the increased re-action. But the advantages of this form would be more felt in its application to hollow projectiles, in which the destructive effects depend more on the quantity of explosive matter they are capable of containing, than on their volume.

Now the content of a cylindrical shot, will be to the content of the inscribed spherical shot, that is, to a spherical shot of the same calibre, and of which the diameter is equal in length to the axis of the cylinder, as three to two, and their weights will be in the same proportion; and as this proportion remains invariable for all calibres, it appears, that, by the adoption of the cylindrical form for shot, without any increased length beyond the diameter of the spherical shot, projectiles of one-half more weight, and containing one-half more explosive matter, may be discharged from artillery of any calibre, than if the projectile were of the spherical form. Consequently, a force equal to that proposed by M. Paixhans for a line-of-battle ship, might be obtained with artillery of a calibre less than what is proposed by him in the ratio of $\sqrt[3]{\frac{3}{2}}$ to 1, that being the proportion of the diameter of a cylinder to that of a sphere of equal content; and although the thickness of the metal only increases as the cube root of the diameter of the bore, this diminution would admit of a much more advantageous disposition of weight, than is proposed by M. Paixhans; besides, if necessary, the same force might be obtained from less calibre, by increasing the proportionate length of the projectile.

Colonel Miller proposes, that instead of the usual method of ignition, by a fusee, the contents of his shells shall be ignited by percussion matter. To accomplish this, the foremost extremity

of the shell is to be terminated by a cone, at the apex of which, an aperture is to be formed, communicating with the interior, to receive a wooden peg, which, on its impact with the object at which the shell is discharged, is to ignite the percussion matter and explode the shell.

However advantageous the cylindrical form may be, we consider this addition utterly inapplicable for the naval service; though we agree with Captain Hastings in the safety of shells on board a ship, we by no means consider that shells which may be exploded by the mere accident of a blow or a fall, to both of which they would be liable from a variety of circumstances, could be admitted there with any degree of prudence. Colonel Miller has certainly proposed a peg to prevent accident, but this is to be withdrawn at the time of loading, when, of all others, there would be most danger of its occurring. In land service, the percussion shell may possibly have its advantages, but in those shells intended for the naval service, a fusee might certainly be substituted with propriety; for however great the precautions may be which are taken, it will be impossible to guard against the casualties which must happen during an action.

That shells will be generally used in the event of another naval war there is scarcely a doubt; what changes their introduction may produce in the nature of that war, it is hard to foresee, probably, as M. Paixhans supposes, an increase in the number, and a diminution in the size of the vessels used. But whatever may be the change in the *materiel* of war, it is on the skill and energy of its application, that the issue of the contest will depend; and thus the same unity of national feeling which has established Britain's naval pre-eminence, will be still irresistibly directed in maintaining it.

TABLE

Of the principal Dimensions of M. Paixhans's Bomb Cannon.

	48-pdr.	80-pdr.	150-pdr.
	In. Line. Pt.	In. Line. Pt.	In. Line. Pt.
Diameter of the bore	6..11..6	8..3..0	10.. 1..6
Length, A B	86..0..0	91..0..0	100.. 0..0
Length of the reinforce, A C	38.. 0.. 0	42..0..0	47.. 0..0
Largest diameter of the reinforce	21.. 2.. 0	24..0..6	25.. 2..0
Least diameter of the reinforce..	18.. 2.. 0	21..0..6	24.. 2..0
Greatest diameter of the chase..	16..10.. 0	19..4..3	22..10..0
Least diameter of the chase	12.. 4.. 0	14..3..0	17.. 3..0
Length of the part, A D........	5.. 0.. 0	5..6..0	6.. 0..0
Diameter of the chamber	4..10.. 0	5. 6..8	6.. 4..6
Length, D E, of the cylindrical part of the chamber........	7.. 3.. 0	8..4..0	8.. 6..0
Length of the part, E F	3.. 3.. 0	4..2..0	5.. 8..0
Length, H B, from the axis of the trunnions to the muzzle	55.. 6.. 0	56..0..0	58.. 6..0
Diameter cf the trunnions......	5.. 9.. 6	6..7..6	9.. 0..0
Length of the trunnions........	5.. 9.. 6	6..7..6	7.. 7..0
Extreme limits of the size of the shell .. maximum	6..10.. 6	8..2..0	10.. 0..6
Extreme limits of the size of the shell .. minimum	6.. 9..10	8..1..3	9..11..8
Thickness of the metal of the shell	1.. 0.. 6	1..1..6	1.. 7..0
Length of the cartridge	9.. 4.. 0	11..2..0	12.. 0..0
Length of the wood bottom	3.. 6.. 0	4..0..0	5.. 0..0
Weight of the shell when empty, calculated to its maximum diameter..................	Pounds. 33	Pounds. 50	Pounds. 102
Weight of the combustible matter contained in the shell when filled	Ounces. 36	Ounces. 64	Ounces. 100

[1] The French inch is ,0886, and the line ,0074 of an English foot. The point is one-twelfth of a line.

PAPERS

ON

NAVAL ARCHITECTURE,

&c.

Art. XXIII.—*Remarks on the Design of Ships.*

The principles on which the qualities of ships depend are now gradually becoming much better known in this country than they have hitherto been. Objections to the application of science to the design of ships have never been considered, by men of sound learning and philosophical attainments, as entitled to respect from any argument adduced in their support; but they are now losing their influence on the opinions of the general observer of naval affairs, although not capable of fully estimating the merits of the claims of science, and of its practical utility: even merely practical men now find it necessary to endeavour to establish their claims on notions of a scientific character. The impropriety of opposing practical knowledge to theoretical investigation is becoming more evident, and the necessity of connecting a scientific practice with scientific reasoning is becoming more generally acknowledged. Theory will soon be no longer a term which its advocates will be afraid of boldly insisting on as the necessary, the only, means of improvement in naval architecture.

The knowledge of naval architecture in other countries is not now to be opposed to the knowledge of this science in England: it is not too much to say, that all that has been discovered in this science in France, Spain, and Sweden, is now known in this country, which possesses peculiar facilities of rendering all this information practically available to its own interests. If it be asked, to what result a general view of all which is known on

this subject leads, we would answer, that it shows that naval architecture is to be regarded exactly in the same light, and to be treated, in its investigation, exactly in the same manner as other sciences; it proves the necessity of the legitimate deduction of a theory from an extensive experience; it shows, that while important truths have been elicited by abstract mathematical reasoning, many other equally important truths have been obscured by the desire of establishing theories on abstract principles; it shows especially that mathematical science is only to be considered as tributary to the general interests of naval architecture, as affording the means of obtaining correct results in its investigation, subordinate to the direction which an extensive scientific experience dictates. That such a theory of naval architecture has not been hitherto established, is to be accounted for only by its requiring time and facilities which no individual can command. The possession of the drawings of all, or, at least, of most, of the ships of his Majesty's navy, with the accounts of their qualities, as far as they have been recorded, would be necessary for the completion of such an object, with the undivided attention of scientific persons devoted to it. We have no hesitation in declaring our conviction that such an analysis of the elements of his Majesty's ships would lead to the improvement of every class of ships in the navy. The improvement of the design of our ships, by this method of investigation, has been earnestly recommended by Mr. Major, in the "Annals of Philosophy," for June, 1825, and for June, 1826; and by Mr. Harvey, in the same work, in the number for January, 1826; and has been constantly insisted on in "Papers on Naval Architecture," from the first article of the first number of this work to the present remarks.

We do not mean to assert that there is any thing new in the principle of this method of investigation, for it is the same which has been adopted since the days of Lord Bacon by astronomers and chemists, and by which most of their valuable discoveries have been made; but that, hitherto, it has not been acted on in the investigation of naval architecture to the extent the nature of the subject requires; nor has the conviction of its necessity obtained that authority, in the minds of those devoted to the improvement of this science, as to render it the

great object of their labours. Such a mode of procedure would, no doubt, check the speculative notions of designs founded on mere hypothesis, and published from the desire of theorising; it disclaims all speculation in the treatment of the science, and claims respect only for that which rests on evidence. Without proof, not one step can be safely taken; with it we are bound to go forward, to obey all its dictates, and to stop only where it is wanting. The rejection of all notions of forms of bodies which "the water likes," is as absolutely imperative as the implicit acquiescence in every result of correct observation and experience. It requires an attentive regard of all that is observable, and the computation of all that is measurable.

So far from such a method of investigating the subject narrowing the limits of inquiry, it points out numberless objects of research, which may be made conducive to its general improvement; and it enables those who will be guided by its principles, although unacquainted with mathematical science, to contribute, in no inconsiderable degree, to its advancement: instead of wasting their labours in useless speculation and opposition to established principles, it shows the advantage which may be obtained by their observations and registry of facts, which others, who might not have the opportunity of making them, may render conducive to practical benefit. It is not unfrequently found, that ships, built from the same design, possess very different qualities; and it is sometimes said, that this proves the futility of theory in ship-building, on the assumption that there are no fixed principles in this science, and that even two ships cannot be built from the same design exactly similar. The latter objection is so utterly inconsistent with the careful practice in his Majesty's dock-yards, in which ships are frequently built from the same lines on the mould-loft floor, and from the same moulds and schemes of scantlings, and with the same timber, that it is needless to deny the unsupported assertion further than by suggesting the propriety of the objector's referring to ships built in the yards from the same design. Let all the circumstances, under which the qualities of the ships have come under consideration, be correctly observed, their draught of water, trim, stowage, and

sails, and it will be found that the disagreement in their qualities may be satisfactorily accounted for. By comparing the reports of the behaviour of these ships, under different circumstances, with their calculated elements, the constructor would be enabled to foretell their behaviour in all cases; and, in accordance with the knowledge thus obtained from experience, to draw up an account of the best stowage, trim, &c.; and when any change should occur in any of these particulars, what alterations should be made in others to counteract the effect. In this manner the defects of a design might be discovered, and the means of correcting them be determined with certainty. Unless the trial of a ship is made with the stowage, trim, &c., intended by the constructor, her qualities cannot be correctly known, and many of her excellencies may remain undeveloped till called into action by corresponding circumstances.

Most of the improvements in the design of ships, which have lately taken place in this country, have been made by this method of scientific deduction and comparison. We may mention, as one evidence, the late improvements in our frigates of 28 guns. With such information as could be obtained from the drawings and reported qualities of the old twenty-eights, Professor Inman constructed the Volage; and, proceeding on the same system of experience, the design of the Sapphire was made, possessing some excellencies wanting in the Volage, and without some defects which the latter ship possessed. Improvement in the design of corvettes, and other classes in our navy, is now proceeding on the same principles.

By reference to the history of our navy, we find that the want of this method of proceeding in the design of our ships of war, in the last century, greatly retarded their improvement. This was particularly evinced in the long continuance of the 44-gun ships in our navy, 38 of which were built between 1740 and 1750, which were deficient in stability, and carried their guns much too near the water. Notwithstanding these defects, 29 more of this class were built in 1774, which so completely failed, even with some attempts made to improve them, that most of them were converted into store-ships. Had their elements been calculated and considered, in reference to their qualities, and been compared with the elements and qualities

of other ships, the exclusion of this class of ships from our navy would have been much earlier than it was. It is a striking evidence that experience, without the assistance of scientific investigation, is long in coming to a just conclusion: it may show defects, but cannot point out the proper methods of removing them. A consideration of the numerous classes and varieties of ships which have composed our navy shows the uncertainty, and the vague notions, which long distracted the means adopted for the improvement of naval architecture in this country. Even when one class of ships was found to answer well, if circumstances rendered a class of greater force necessary, we do not find that the experience derived from the behaviour of the first class led to the means of giving the new class even the same good qualities.

We will endeavour briefly to explain the manner in which the design of ships should be conducted in connexion with the necessary deductions from experience. In the first place, the number of guns and weight of metal which a ship is to carry must be determined. It may be observed, that the advantage of heavy metal is generally acknowledged, and that the effect of a certain number of guns, of large caliber, is greater than an increased number of guns of smaller caliber, the sums of whose weights are equal. The limit to the weight of metal on board ships depends on the strength of the ships' sides and decks, and on the convenience of managing them in action. With respect to the first consideration, mechanical science shows that the strength of our ships may be rendered capable of sustaining the recoil of guns of greater weight than are at present used. Whether shot of greater weight than those which constitute, generally, the force of the lower decks of our line-of-battle ships, may not be advantageously used in our three-deckers, and large two-deckers, appears questionable: it is a subject, however, requiring the attention of those officers whose experience in naval engagements peculiarly qualifies them for its consideration. The celebrated Chapman considered, from the experience obtained in the war between Russia and Sweden, in which the Swedish sailors managed 36-pounders with great ease, that the size of shot on board ship might be advantageously increased. The following table gives the armament

of the three largest classes of ships which he proposes, in his "Treatise[1] on Ships of War."

Guns.	110		94		80	
	No.	Pdrs.	No.	Pdrs.	No.	Pdrs.
On the first deck	30	[2] 48	30	42	30	42
——— second deck	32	36	32	30	32	24
——— third deck......	30	24	32	18	—	—
——— quarter-deck & forecastle..	18	12	—	—	18	12
	110		94		80	

Chapman insists on the strength and hardihood of the *Swedish* sailors enabling them to manage the larger guns with ease: at least equal capabilities may certainly be assigned to British sailors; and it is probable, that in respect to the use of large shot in future naval engagements, the superiority of the *personnel* of our navy over that of the Southern nations of Europe, may afford permanent and important advantage.

When the number and sort of the guns are determined, their total weight, with that of the ammunition and furniture, is known. The displacement of the ship, which is the first element of the design, may then be obtained; this is equal to the total weight of the armament; of the crew, whose number depends on the guns, with the provisions and stores; of the ballast; and of the hull of the ship, with the masts, yards, rigging, &c. An error in this element may be fatal to the design. It has not unfrequently happened, that by constructing a ship, without due attention to the load displacement, when stored and fitted for sea, it has been found to carry the ports much too near the water, which could be corrected only by reducing the

[1] This work has never been published in any language but Swedish. Its practical importance has induced the writer of these remarks to make a translation of it into English, which is intended for publication.

[2] 1000 Swedish lbs. = 937 English lbs.

proper complement of stores and provisions. To enable the constructor to determine with certainty the displacement of a ship, tables of all the weights which it comprises should be accurately given in detail. The weights of the hulls of all ships should be ascertained from their light displacement, calculated from their drawings, to their draught of water when launched, which should be registered, with an account of the kind of timber of which they were built, and with all circumstances which may affect their weight. The load displacement also of all ships should be calculated from their drawings, at their draughts of water, carefully taken when stored both for channel and foreign service, with an account of all the weights on board, and of the height of the ports above the water's surface, which should be registered in the tables. By means of such tables, constructors would be enabled to design a ship with perfect confidence that the proposed draught of water, and height of ports, would agree, to a great degree of exactness, with the actual draught of water and height of ports of the ship when completely fitted for sea.

When the displacement is thus obtained from the sum of the weights of the ship and lading, the principal dimensions, the length and the extreme breadth of the load water-line, and the depth from the water to the lower edge of the rabbet of the keel, must be determined. These dimensions, together with the form of the body, the displacement remaining constant, must be fixed in relation to the particular qualities which the service for which the ship is intended may require: either velocity, burden, or for such a combination of qualities as the general service of his Majesty's ships renders necessary. It cannot too often be insisted on, that some qualities cannot be possessed by any ship, in a very eminent degree, without a corresponding sacrifice of others. It is the department of science, by an acquaintance with the principles on which they depend, to regulate the elements of the design so as to ensure the possession of such qualities, and in such a degree, as may be required. The length is the first dimension to be determined from the displacement, and this can be done with certainty only by reference to ships of a similar description, whose elements are known, and whose behaviour, under various circumstances, have been accurately observed; such alterations

being made by the constructor as he may, from his experience and knowledge, consider conducive to the excellency of the design. The length will then be given in terms of the displacement, and in relation to the other dimensions and elements, and, consequently, in accordance with all the qualities of the ship. A most extensive acquaintance with the elements and qualities of ships is evidently necessary to enable a constructor to design a ship in this manner, so that it shall possess all the excellencies which the experience of the present time offers. This is the principle on which the perfection of the design of ships is founded; that is, not the perfection which the laws of nature limit, but that perfection which the present development of those laws affords. Chapman gave, as the result of his experience, the length of the construction water-line of ships of the line, $L = 5 \cdot 2033\ D^{0,3088}$, D representing the displacement to the outside of the timbers; and the breadth of this water-line for three-decked ships $= \frac{L^{0,9947}}{3,5863}$, and for two-decked ships $= \frac{L^{0,8391}}{1,5767}$. Further experience might have led him to alter these proportions in relation to any change in the armament which might take place, or to any other change in the nature of the fitting: his experience was, however, very great; and the very excellent designs he has left us evince his very extensive knowledge of the subject, and place him at the head of the profession of naval architecture;—and we do not hesitate in assigning him the rank of the first constructor the world has hitherto known. Since his time the subject has not been prosecuted on the same principles with equal devotedness, if with equal talents.

The whole theory of the science is included in such a process; the stability, proper adjustment of the masting, the form conducive to easy motion of pitching and rolling, are involved in this method of design; not on speculative opinions, but on the known and certain principles which govern the properties of floating bodies. It is not opposed to experiment; but it does not leave us to consider every new design of a ship as an experiment whose qualities are left to trial to determine. When experiments are made, it appropriates to itself the knowledge obtained from their results, and thus keeps up the

practice of the design of ships agreeably to every new acquisition of knowledge on the subject.

The method of proceeding with the design of a ship, by determining the length of the lower gun-deck, previously to the displacement, from the number of guns, the distance between them, and the length abaft the aftermost and before the foremost posts, is incorrect[1]. If the length be first fixed, the breadth must be determined in relation to it, so as to ensure a proper moment of stability; the depth is limited, in a great degree, by the draught of water, it may be necessary not to exceed in accordance with the service of the ship, and the seas and harbours it is destined to navigate, observing, at the same time, that the depth is sufficient to prevent great lee-way; the fulness of the body is determined in reference to the velocity, lee-way, and weatherly qualities; so that the displacement becomes thus determined from these elements, independently of the necessary weights of the hull and lading, with which it may not agree. If the length be fixed in relation to the number of guns on the lower gun-deck, and the necessary breadth is given in relation to the length, and if the displacement is determined from the whole weights of the ship, the only variable elements in the construction which can render these data consistent with each other, even in respect of magnitude, are the depth and the fulness of the body; but, with respect to the qualities of the ship, such a variation of these two elements may be very injurious to the excellency of the design.

It follows, from these considerations, that there are limits to the number of guns which should be placed on each deck in proportion to the whole armament of the ship, in dependence on the unity and harmony of the design, in obtaining the maximum of excellence agreeably to the present experience and knowledge of the science. We conclude, then, that the proper manner of making the design of a ship is, first, to fix on the total weight of metal it is intended for her to carry; and from this weight, with all the other weights of the ship, to obtain, by calculation, the proper displacement; and from this displacement to determine the relative proportions of the ship,

[1] Chapman's work on Ships of War, page 13.

agreeably to our acquaintance with the laws of floating bodies, and from our experience of their effects on ships whose qualities have been carefully observed.

When the proper displacement is determined, the next consideration is the stability, the most important quality of a ship. Not only should the moments of stability at different angles of inclination of all ships be accurately calculated and registered in tables, but the values of the different elements of which the whole moments are composed should be given in detail; the volumes of the body immersed and emerged at different angles of inclination, the distance between the centres of gravity of these volumes, the distance of the centre of gravity of the displacement below the water-line, and from the middle of the length of the water-line, and the situation of the centre of gravity of the ship and lading. The necessity of obtaining the last element, the situation of the centre of gravity of ships, has been frequently insisted on, as, without it, few of the qualities of ships can be correctly found; and several practical methods have been given for determining it; and we trust that this element will soon be found for all classes of ships in his Majesty's navy.

In addition to the height of the centre of gravity of the ship, it would be very useful to have the distance it would be moved in each class of ships by raising or lowering a certain weight to a given distance, and the effect it would have on the moment of the stability. The effect also should be known which would be produced on the moments of stability of ships of each class, by increasing the breadth a certain quantity; the new curve of the side being given in relation to the curve of the side before the alteration, and assimilating with the former curvature of the body at a given distance above and below the water-line.

The moments of the sails should also be given for all the ships, to be compared with their moments of stability. The length of the masts and yards should also be given, with the areas of all the sails in detail, the position of their common centre of gravity, the relative proportions of the moments of the fore and after sails, with the relative fulness of the whole body, and of the fore and after parts. This relative fulness of the body may be shown either by the exponential system of

Chapman; by the relation between the whole displacement and the fore and after parts of the displacement, with the circumscribing parallelopipeds; or by the positions of the centres of gravity of the whole displacement, and of the fore and after parts of the body, both in respect to length and depth. The areas of the midship sections, with the characteristics of their form, should also be given. In short, the tables of elements should be so complete that a perfect knowledge of the form of the ship might be obtained from them; so that a ship might be constructed exactly similar to any one of those from which the calculations were made. Unless these data are complete, there would be but little advantage to be obtained from them by the constructor, in enabling him to form new designs of ships, avoiding the errors of the originals, and increasing or diminishing any quality at pleasure.

In connexion with the tables of elements, the results of the observations made at sea on the behaviour of the ships, under all circumstances, should be registered. These observations should be so well directed, and so extensive, that every quality of a ship may be distinctly shown, and its action, in all kinds of weather, clearly explained. Those which are at present made on board his Majesty's ships at sea are valuable, as far as they extend, but there are numerous other particulars which require to be attended to in order that the experience of naval officers may conduce to the improvement of naval architecture in that eminent degree to which it may be rendered available. We intend to embody the particulars of several tables we are in possession of, and to add some other heads, under which we consider observations should be made on ships at sea, for the future improvement of their design, in an early number of this work. The superior system of education now afforded to many naval officers at the college in the dock-yard at Portsmouth, especially qualifies them for making these observations in such a scientific manner as to render their experience extensively applicable to the interests of naval architecture. In addition to many important advantages which will arise from a superior order of scientific education, its effect will be greatly to extend the true principles of naval architecture: it will check speculation, correct undefined notions, and show that the legiti-

mate method of improving this science is by the use of mathematical science practically applied to the calculation of ships' elements, in connexion with scientific experience. If this increased knowledge of the subject should only check the too prevalent desire of theorising, it would be useful; but it will do much more: it will suggest objects for observation in numerous circumstances hitherto unnoticed, or imperfectly observed; it will establish the importance of accumulating facts for the use of the naval architect; and, with the knowledge of the principles on which the action of ships depends, it will show the propriety of noticing many minor circumstances attending the observation, without which the knowledge of a mere isolated fact would be much less useful. We would not attempt to argue that naval officers can become naval architects, as we well know that nothing less than a long and laborious course of studies, with undivided attention to the subject, can qualify for the design of ships; yet we look forward with confidence to the result of the scientific experience of naval men, as greatly tending to perfect the knowledge of naval construction. In any other science, he who forms a design, by a combination of its established principles, regulated by his judgment, agreeably to his intended object, may himself witness the effect of his labours; but, in ship-building, the constructor not only obtains much of the knowledge he uses in the design of a ship from the experience of others, but is, in many instances, in a great degree, obliged to depend on the observations of others for the esult of his labours in each particular design. Hence arises the importance of naval officers being, as far as circumstances permit, acquainted with the principles of the design, in order that their experience may be practically useful in scientifically observing the qualities which the ship was intended particularly to possess.

Among all the authors on naval architecture, Chapman is the only one who has followed this method of investigation to any great extent; and to this we consider the superior usefulness of his works may be attributed.

We are aware that an objection has been made by some of our readers to the usefulness of this work, on account of the quantity of mathematical analysis in many of the papers, and

because the arithmetical calculations of the different elements have not hitherto been given in detail. We shall endeavour partly to obviate this objection, by giving, in our future numbers, a series of papers, including, not only the mathematical investigation of the different elements of ships, but their practical application, with an example of the method of making all the necessary calculations for the design of a ship. In these papers, we hope clearly to show the necessity of scientific investigation, with its application to practice, and to explain the whole process of the design of ships, agreeably to the knowledge which is now possessed in this science. The use to be derived from the experience of naval officers will also be shown in connexion with the different elements which will come under consideration, and their influence on the good qualities of the construction.

Art. XXIV.—*On the Form best calculated for Velocity.*—*By* George Bayley, Esq. *of Ipswich.*

It is matter of regret, that the attention of English Mathematicians has not been more engaged in the elucidation of a point in Naval Architecture, which has never yet received a clear and satisfactory demonstration; at least the writer of this paper has never yet met with one which was satisfactory to his own mind:—namely, whether or not there is a geometrical curve which is always to be found in all fast-sailing vessels? Another important point has not received that attention which it deserves, namely, the direction in which the fluid passes along the bottom of a vessel.

It may be supposed that this last question is unimportant, and easy of solution. It is undoubtedly of the utmost importance, nay, essential, that we should know the direction of the force, before we can estimate with correctness the amount of the resistance. Chapman has given a method for calculating the resistance of bodies of various forms, which, ingenious as it is, is only a guess at the truth. He seems altogether to have left out the consideration of the change which takes place in

the direction of the particles of the fluid, before they impinge upon the bottom. That their direction is altered before they do impinge upon the bottom, is evident to any one who takes the trouble to watch the progress of a vessel in smooth water; and that they are differently affected by different vessels is also evident; but the causes of this difference do not appear to have been sufficiently investigated. We have found that, by forming the bow more acute, the vessel has less resistance to overcome in passing through the fluid, than if more full and bluff: with this scanty knowledge we have been content, and have not followed out the subject so as to ascertain precisely what acuteness and what curvature should be given, in order that the vessel may have the greatest possible velocity, consistent with the purpose for which she is intended.

It has been stated with confidence upon the authority of the experiments made in 1796 and 98, "That a long parallel body, terminating at each end in a parabolic cuneus, is the form best calculated for velocity." The experiments referred to are valuable so far as they go, but they were not carried far enough. The experimentors seem to have contented themselves with ascertaining the effect, which ends of certain given forms would have upon the velocities of different bodies, whose transverse sections were of equal areas; but they seem wholly to have overlooked, or neglected, the consideration that the fluid, in passing by a floating body, does not move in a horizontal direction only; for it does not appear that they made any experiments with models, whose ends were formed by known curves in an oblique direction, similar to that in which the fluid *would* pass by them.

Experiments of this kind are still necessary, in order to obtain correct data for the construction of ships, which of all possess the requisite qualities in the largest proportions, consistent with the purposes for which they are designed. If, for instance, it were required to build a vessel of a certain length, breadth, and depth, to carry a certain number of tons, it would be highly advantageous for the constructor to be in possession of some rule, by which he might render a vessel of this kind as fast as it is possible for her to be with the given burthen.

The requisition is one of frequent occurrence to merchant

ship-builders. How they are able to comply with it, let the state of our mercantile navy answer: there we see ships of the same dimensions, register-tonnage, and actual burthen, whose sailing qualities are totally different. In this case it cannot be the difference of the area of the midship section which makes them differ so widely. The difference must, therefore, be in the form of the ends; but as their displacements are the same, the difference must necessarily arise from the forms of the curves which describe the bows and quarters. The case here alluded to has occurred frequently within the writer's knowledge; and, in one instance, the difference in the ratio of sailing amounted to one-third. The frequent difference found in the ratio of sailing between vessels having the same dimensions and displacement, has induced the writer carefully to examine and compare the curves given by different longitudinal sections of such vessels, in order, if possible, to discover whether there was any one section of the same general character which would be found in all the fast vessels, but not in the slow vessels. The result has been as was expected. In vessels which have come under the writer's notice, having a rising floor, the same distinctive character has been traced in the lines of those vessels which possess superior sailing qualities. The section, in which it is believed the curves of all fast-sailing vessels will be found to agree in character, is that made in the direction of the passage of the water by the vessel. But it is evident, that if our attention be confined to the form best calculated for smooth water, we may fail in producing a vessel which will sail fast in bad weather against a heavy sea. In most, if not in all, the experiments which have been made to ascertain the velocity of floating bodies, the centre of effort of the propelling force has been but little elevated above the surface of the water; but, in actual practice, the centre of effort of the sails is sufficiently raised above the surface of the water to produce a sensible depression of the bow, under certain circumstances. Now it is well known, that in fast-sailing vessels an alteration in the line of floatation, a few inches either way, will affect their velocity more or less. The cause of this has not yet been satisfactorily demonstrated; and a set of experiments would be valuable, which should demonstrate the form whose velocity is least affected by a power

acting at the point where the centre of effort of the sails would be. In cutters, and other fast-sailing vessels, the form of the bow, above the water, is by no means an unimportant consideration. Vessels of this description, it is well known, are frequently much impeded in their progress through the water to windward, by the shocks of the waves: attempts have been made to remedy this defect, by making them very lean aloft; but in avoiding one evil they have frequently fallen into another, which is of equal or greater magnitude—that of making them pitch heavily, for want of sufficient buoyancy forward. It is certainly the fact, that there are fast-sailing vessels which rise easily in the sea; such vessels have what is termed a long bow, which, however, possess more relative buoyancy than many others which are not nearly so acute at the extremities.

In all the vessels which have come under the notice of the writer, as remarkable both for their velocity and easy motion at sea, he has observed what he believes to be a characteristic form of all fast and easy vessels. It may be described to be a segment of a parabola, in the section given by an imaginary line drawn upon the bottom, in the direction in which the water passes by the vessel. Such vessels have, generally speaking, long and easy bows, compared with others of the same class whose lines have not this parabolic curve.

The suitability of curves of this kind for easily dividing the fluid, is evident on inspection. They displace, at first, proportionally, a much larger volume of the fluid, and of course with less resistance than curves of a different form, and, therefore, the direct resistance is much less; for, as it is clear that the ratio of the resistance of a volume of water increases much faster than its area, so ought the angle of incidence to be decreased.

It may be thought presumptuous for any one so little known as the writer of this paper, to make his remarks so freely upon a subject which is confessedly a difficult one, to which the attention of abler men than himself has been directed, at different times, without success. His excuse must be an ardent desire to see the true principles of naval architecture clearly demonstrated, and the profession, of which he is a member, rescued from that reproach of empiricism, which is too justly charged upon it.

Art. XXV.—*Report of the Committee for conducting the Experiments of the Society for the Improvement of Naval Architecture, at the Greenland Docks, from the year* 1796 *to* 1798, *inclusive.*

Part I.—Chap. I.—*Definitions*[1] *and Explanatory Observations.*

By *head pressure,* we mean the total pressure which exists against the head end or foremost part of a body, immersed, either wholly or in part, in any given fluid, when such body is at rest.

By stern pressure, we mean the total pressure which exists against the stern end, or hindermost part of a body, immersed, either wholly or in part, in any given fluid when such body is at rest.

By plus pressure, we mean the additional pressure which is sustained by the head end, or foremost parts of a body, moved through a fluid; which additional pressure is over and above what we have termed the head pressure, and arises from the fluid being obliged to be displaced, in order to permit the moving body to pass through it.

By minus pressure, we mean a subtraction of pressure from the stern pressure, and which subtraction is occasioned by the fluid not pressing so strongly against the stern end, or hindermost parts of a body, when such body is in motion through the fluid, as when the body is at rest.

By friction, (as relating to this subject,) we mean that sort of resistance to a body moved through a fluid, which arises either from the adhesion of the particles of the fluid to the surface of the moving body, or from the roughness of the body, or from both those causes united.

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[1] The definitions, from one to six, inclusive, were drawn up by our ingenious Vice President, Earl Stanhope, in the year 1795. These, in our opinion, are well conceived, and also perfectly consistent with the laws of nature as relative to this subject.

By total resistance, we mean the sum total of the plus pressure, the minus pressure, and the friction, united.

By head resistance, we mean the minus pressure, and the friction of the water against the head end united.

By stern resistance, we mean the minus pressure, and the friction of the water against the stern end united.

Having procured two bodies, called the long friction plank, and the short friction plank, (which were of the same degree of smoothness, and also of the same breadth and thickness, and of the same form in every respect, except in length,) for the purpose of ascertaining the effect or resistance arising from the friction of the water; and also other bodies, with the same middle part and head end, but with differently formed stern ends, for the purpose of ascertaining the effect of the stern resistance, and the minus pressure; and also other bodies, with the same middle part and stern end, but with differently formed head ends, for the purpose of ascertaining the effect of the head resistance, and the plus pressure.

All these different bodies were planed smooth, and painted white: and the form and dimensions of the said bodies are respectively represented in plates 5 and 6.

The bodies which are represented in table 1, of the first part[1] of the Report, were respectively immersed, by means of the conductor, and its bar, or bars, to the medium depth of six feet under the surface of the water; and when they were so immersed, the conductor swam with its top, or horizontal upper surface, exactly one inch above the surface of the water; but the bodies which are represented in table 1, of the second part[2] of the Report, were only immersed so as to keep the top, or horizontal upper surface, just even or level with the surface of the water when in motion. All of these bodies were respectively drawn through the water by means of certain weights or motive powers; which motive powers, and also the velocities produced therewith, are respectively shown in table 1. The

[1] The first part of the Report contains the experiments of the years 1796, 1797, 1798; and the second part contains the experiments of the years 1793, 1794, 1795.

[2] Unfortunately this second part has never been published.—Ed.

motive powers[1] are in the top columns, and the velocities produced therewith are in the same columns underneath, and directly opposite to the bodies to which the velocities do respectively belong.

Having obtained a set of velocities by experiment with each of the said bodies as respectively represented in table 1, it then became necessary to examine and compare the said experimented velocities and resistances, in order to search out the laws which belong to the different sets; which examination has been made according to the method specified in the following chapter.

Chap. II.—*Examination of the Experimented Velocities, to search out the Law of Resistance which belongs to the different Bodies.*

For this purpose we shall select, by way of example, the set of experiments with the conductor, its bar, and the long friction plank, as found in table 1, (page 386.) The numbers run thus :—

Motive powers in pounds	12	24	36	48	60	72	96	120
Velocities in feet per second	3·408	4·888	5·847	6·668	7·420	8·161	9·327	10·310

We have selected this set, because it contains a great number of experimented resistances.

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[1] The motive powers or resistances are always specified in pounds avoirdupois.

Now it is first necessary to try, in what powers of the velocity the several motive powers or resistances are; namely, by comparing together every two experiments: that is, first the 120lb. with every weight resistance less than it; then the 96lb. with every weight or resistance less than it; and so on, till every combination of two's has been made.

This examination may be best made in a manner similar to Mr. Garnett's[1] theorem, viz. as $V^m : v^m :: R : r$; making the resistance proportional to some power of the velocity, which power, or exponent m, is found by this rule, viz.

$$m = \frac{\log. R - \log. r}{\log. V - \log. v}.$$

Computed thus:

EXAMPLE I.

$$\begin{array}{lllll}
\text{Motive powers} & \left\{ R = 120 \right. & \log. = 2 \cdot 07918 & & \\
\text{or resistances} & \left. \quad r = \ \ 96 \right. & \log. = 1 \cdot 98227 & & \\
 & & \text{differ.} = 0 \cdot 09691 & & \log. = \bar{2} \cdot 98637 \\
 & V = 10 \cdot 310 & \log. = 1 \cdot 01326 & & \\
 & v = \ \ 9 \cdot 327 & \log. = \ \ \cdot 96974 & & \\
 & & & \text{differ.} = 0 \cdot 04352 & \log. = \bar{2} \cdot 63869 \\
 & & & & \text{differ.} = 0 \cdot 34768
\end{array}$$

The natural number to this log. is 2·2268, which is the exponent m, or the index of the power of the velocity.

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[1] We think it necessary to observe in this place, that in the course of conducting the experiments since the year 1794, we have constantly used Mr. Garnett's theorem to compare the resistances of the bodies, and have found it to answer exceedingly well. But in order to give it a further investigation, we, some time ago, submitted a great number of experiments, together with this theorem, to the inspection and consideration of our learned friend and member of this Society, Dr. Hutton, F.R.S. and Professor of Mathematics at the Royal Military Academy at Woolwich, and requested him to favour us with his opinion thereon; when he very obligingly presented us with a written paper on the subject, and which is given in substance in this chapter.

EXPONENTS.

120 with 96 =	2·227
72 =	2·185
60 =	2·107
48 =	2·107
36 =	2·123
24 =	2·157
12 =	2·080
96 with 72 =	2·154
60 =	2·055
48 =	2·065
36 =	2·100
24 =	2·146
12 =	2·065
72 with 60 =	1·915
48 =	2·007
36 =	2·079
24 =	2·143
12 =	2·050
60 with 48 =	2·088
36 =	2·144
24 =	2·195
12 =	2·069
48 with 36 =	2·190
24 =	2·232
12 =	2·066
36 with 24 =	2·263
12 =	2·035
24 with 12 =	1·922
Sum =	58·969
Mean = m =	2·1060

Now, by applying the aforesaid rule to all the above numbers, the several values of *m*, or the exponents of the power, come out as shown in the margin.

These values of *m*, it is evident, are various, but the variation is small, and vibrates as it were each way; which indicates that the law of the resistance is constant or regular, and that these irregularities in the values of *m*, or exponents, proceed from small deviations or irregularities in the experiments themselves.

It may, therefore, be advisable to take a medium amongst them all, and by means of it reduce the experimented numbers into a regular series. Now, for this purpose, adding together all these 28 exponents, and dividing the sum by 28 (the number of them), the quotient is 2·1060, which is the mean value of *m*.

Now, the nearest calculated exponent to this value of *m* is 2·107, found from the numbers 120 and 60, and also from 120 and 48. Assuming, therefore, either of these terms, 120, 60, or 48, and their correspondent velocities, 10·310, or 7·420 or 6·668, and from thence computing the velocities answering to all the other weights or motive powers, the unavoidable irregularities in the experiments will thus be brought into a regular series. Computing them then in this way, they come out as follows :—

Motive powers in pounds..	12	24	36	48	60	72	96	120
Velocities in feet	3·455	4·801	5·821	6·673	7·419	8·090	9·273	10·310

All which velocities are computed by this theorem, viz.

$v = V \times \sqrt[m]{\frac{r}{R}}$; or log. $v =$ log. $V - \frac{\text{log. } R - \text{log. } r}{m}$. Wherein $R = 120$, $r = 96$, $m = 2 \cdot 1060$, and $V = 10 \cdot 310$. Computed thus:

EXAMPLE II.

$R = 120$ log. $= 2 \cdot 07918$
$r = 96$ log. $= 1 \cdot 98227$
$0 \cdot 09691$ log. $= \bar{2} \cdot 98637$
$m = 2 \cdot 1060$ log. $= 0 \cdot 32346$
differ. $\bar{2} \cdot 66291$ nat. numb. $= 0 \cdot 04602$
$V = 10 \cdot 310$ log. $= 1 \cdot 01326$
differ. $0 \cdot 96724$

The natural number to this logarithm is $9 \cdot 2734 = v$, which is the velocity per second correspondent to the motive power or resistance of 96lb.

The above series may be considered as the correct or regular series of experiments, with the conductor, its bar, and the long friction plank; and in like manner may be computed the velocities correspondent to other proposed resistances.

And the resistances to proposed velocities are computed by this theorem, viz.

$R = r \times \left(\frac{V}{v}\right)^m$; or log $R =$ log. $r + \overline{\text{log. } V - \text{log. } v} \times m$; wherein $r = 120$, $m = 2 \cdot 1060$, and $v = 10 \cdot 310$, and $V = 13 \cdot 5275$, the velocity in feet per second, which answers to 8 nautical miles per hour. Computed thus:

EXAMPLE III.

$V = 13 \cdot 5275$ log. $= 1 \cdot 13122$
$v = 10 \cdot 3100$ log. $= 1 \cdot 01326$
$0 \cdot 11796 = \bar{1} \cdot 07173$
$m = 2 \cdot 1060$ log. $= 0 \cdot 32346$
Sum $= \bar{1} \cdot 39519$ nat. numb. $= 0.24842$
$r = 120$ log. $= 2 \cdot 07918$
Sum $2 \cdot 32760$

The natural number to this logarithm $= 212 \cdot 618 = R$, which is the resistance of the conductor, its bar, and the long friction plank, for the velocity of 8 nautical miles per hour. And in

like manner may be computed the resistance correspondent to any proposed velocity.

So that the regular series of velocities as given in the columns of table 1 have been computed according to example 2; and the resistances correspondent to the velocities of from 1 to 8 nautical miles per hour, as given in the columns of table 1, have been computed by example 3.

Velocity in feet per second.		Nautical miles per hour.
1·6909	is equal to	1
3·3819		2
5·0728		3
6·7638		4
8·4548		5
10·1456		6
11·8366		7
13·5275		8

Chap. III.—*On the finding the Friction.*

Having (by the method specified in example 2 of the preceding chapter) found the motive powers requisite to bring the different bodies to exactly the same rates of velocity, viz. from 1 to 8 nautical miles per hour, and as found in table 1. Then the next object which is necessary to be obtained, is to ascertain the resistance arising from the friction of the water against the several surfaces of the different bodies respectively.

Now, for this purpose, it will be seen, by inspecting the form and dimensions of the friction planks, as used in the experiment of 1798, in table 1, plate 5, that the long friction plank was exactly 12 feet longer than the short friction plank; and that they were of the same degree of smoothness; also that they were exactly similar in the form and dimensions of their head ends and stern ends; or that they were similar in every respect except in length. From whence it is evident, that whatever difference arises between the resistance of the two planks, such difference must be the resistance arising from the

friction alone of the water against 46 square feet of surface, which is the surface contained in the long friction plank more than in the short friction plank.

Therefore, the difference between the resistances of the two friction planks, (which is equal to the friction of the water against 46 square feet of surface, as aforesaid,) is accordingly found in table 2; and from thence the motive powers requisite to overcome the resistance arising from the friction of the water, which takes place against the several surfaces of the different bodies, have been computed, according to the proportion which the said surfaces respectively bear, to 46 square feet, as found in table 2.

Chap. IV.—*On the Resistance sustained by the different Bodies, when considered as Ships, or navigable Vessels; with comparative Observations relative to the Advantages or Disadvantages, arising from the Form, with respect to the relation which the Resistance bears to the Capacity, and to the Stability or Power of carrying Sail, and also to the Vis Insita Force*[1].

It has been already shown, that the bodies used in the years 1796 and 1798, were respectively immersed to the medium depth of six feet under the surface of the water; then, in order to make comparisons with the said bodies, considering them as ships, or navigable vessels, it is first necessary to deduct the friction which takes place against the top surface of the said bodies, as found in table 2, from the total resistance as found in table 1;

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[1] Vis insita, or innate force of matter, is a power of resisting, by which every body, as much as in it lies, endeavours to persevere in its present state, whether of rest or of moving uniformly forward in a right line.—This force is always proportional to the quantity of matter in the body, and differs in nothing from the vis inertiæ, but in our manner of conceiving it.—See Hutton's *Mathematical Dictionary*, Art. Vis Insita, &c.

then the remaining numbers will represent the resistance sustained by the different bodies, when considered as the immersed part of ships, or navigable vessels.

The said deductions are accordingly made in table 3; and the motive powers requisite to overcome the resistance of the different bodies, when considered as ships or navigable vessels, is therein found.

In the experiments of the year 1798, the bodies Ao, Aa, &c. to Ai, were constructed for the purpose of ascertaining the advantages or disadvantages arising from their several differently formed stern ends. Now, by inspecting the resistances of the bodies Ao and Aa, (as ships,) and found in table 3, it will be seen that the resistance of the body Aa is a little less than the resistance of the body Ao; and also, that the resistance of the body Ha, is a little less than the resistance of the body Ho; which curious circumstance arises, in each case, from the stern end o, having a greater surface for friction than the stern end a.

From whence it is evident, that the resistance arising from the friction against the stern end o, is greater than the friction and minus pressure together of the stern end a.

It will also be seen, by inspecting table 3, that the resistance of the body Ab, (as a ship,) is a little less in the velocities from five miles per hour downwards, than the resistance of Aa; but in the higher velocities the body Aa has the least resistance.

This crossing is occasioned by the law of the stern resistance of the stern end b, increasing in a greater ratio than the stern resistance of the stern end a; and which probably arises from the angular part of the stern end b, (that is from s to b,) being more obtuse than that of the stern end a.

And with respect to the bodies Ac, Ad, &c. to Ai, it will be seen, that they have all greater resistances than either of the aforesaid bodies Ao, Aa, or Ab; which are disadvantages that evidently arise out of the form of the stern end of the said different bodies respectively; and of which the stern f, of the body Af, has the greatest disadvantage, or is the worst stern end of all.

The bodies Aa, Ba, Ca, &c. to Ia, were constructed for the purpose of ascertaining the advantages or disadvantages arising from their several differently formed head ends.

Now, by inspecting the resistance of the said bodies (as ships) as found in table 3, the comparative advantages or disadvantages, arising from their several differently formed head ends, will readily be seen; that is, so far as concerns the resistances only.

But in the investigation of this subject, that is, considering the said bodies as representing ships, it must be noticed, that the said different bodies have different magnitudes, and, consequently, different degrees of stability, or stiffness, to carry sail; and also the relation which the resistance bears to the capacity, or the relation which the resistance bears to the vis insita force, or power of going forward, and the momentum will be different in each body.

Then, taking the subject in this point of view, it of course becomes necessary to ascertain the relation which the resistance bears to the capacity, and also the comparative degrees of stability of the different bodies respectively: and from thence we shall be enabled to draw proper conclusions respecting the said bodies, as applicable to practice.

And as the said bodies are of the same form and dimensions in their midship section, and only differ in length, and in the form of their head ends and stern ends; therefore their comparative stability will be nearly in proportion to the capacities of the different bodies respectively.

From whence it is readily conceived, that the comparative power, or quantity of sail, which the different bodies are capable of sustaining, will also be nearly in proportion to the capacities of the different bodies respectively.

And the capacities of the different bodies, when considered as ships, or as a column of water, are found to be as follow:—

		lb.		*lb.*		*lb.*
Weight of the following bodies as a column of water.	Ao	=294 ·37	Ad or Da	=215 ·63	Ah or Ha	=179 ·37
	Aa	=247 ·50	Ae or Ea	=199 ·37	Ai or Ia	=155 ·00
	Ab or Ba	=266 ·25	Af or Fa	=181 ·87	Ho	=226 ·25
	Ac or Ca	=300 ·00	Ag or Ga	=193 ·13	Io	=201 ·87

Then, by taking the resistances of the said bodies, say at the velocity of five miles per hour, as found in table 3, and placing them as numerators; and also by placing the capacities or weights of the said bodies, as found above, under their correspondent resistances, as denominators; then the numbers so

placed will represent the relation which the resistance bears to the capacity, and also the relation which the resistance bears to the stability, as also the relation which the resistance bears to the vis insita force, or power of going forward (or to the momentum) all which relations are as follow:—

		lb.			*lb.*			*lb.*
Ao	Resistance =	16·45	Da	Resistance =	17·61	Ha	Resistance =	18·77
	Capacity =	294·37		Capacity =	215·63		Capacity =	179·37
Aa	Resistance =	16·31	Ea	Resistance =	19·91	Ia	Resistance =	61·47
	Capacity =	247·50		Capacity =	199·37		Capacity =	155·00
Ba	Resistance =	15·23	Fa	Resistance =	23·49	Ho	Resistance =	19·02
	Capacity =	266·25		Capacity =	181·87		Capacity =	226·25
Ca	Resistance =	17·12	Ga	Resistance =	16·23	Io	Resistance =	61·35
	Capacity =	300·00		Capacity =	193·13		Capacity =	201·87

For the sake of comparing the above numbers more readily, they have been considered as fractions, and reduced to their lowest terms, from whence the relation which the resistance bears to the capacity, or the capacity to the resistance, &c. &c. will be as follows:—

	Ao	Aa	Ba	Ca	Da	Ea
Resistance ..	1	1	1	1	1	1
Capacity	17·895	15·175	17·482	17·523	12·244	10·014
	Fa	**Ga**	**Ha**	**Ia**	**Ho**	**Io**
Resistance ..	1	1	1	1	1	1
Capacity	7·743	11·899	9·559	2·522	11·895	3·291

Now, by inspecting the above numbers, it appears, that the relation which the resistance bears to the capacity (or to the stability, or to the vis insita force) is nearly the same in the bodies Ao, Ba, and Ca; that is to say, if their respective resistances be equal to 1, then the capacity or stability, or vis insita force of Ao, is 17·895, of Ba, 17·482, and of Ca, 17·523: from whence it appears, that the body Ao has the greatest advantage, and the body Ca, the next greatest advantage. But, supposing the said bodies to be ships in motion at sea, then it may fairly be inferred, that the body Ca would be the worst of the three bodies; because the head end of the

body Ca would not meet with so much lateral resistance, to keep the body to windward; and it would meet with more resistance in its pitching motion, than either of the bodies Ao, or Ba.

We have thought it advisable to say thus much respecting the method of comparing the results of the experiments with the said bodies, in order to prevent persons who might not have had an opportunity of considering the subject fully, from drawing their conclusions, by comparing the resistances only; and for which reason it might be proper to make further comparisons by way of illustration. Now, for this purpose, we shall compare the resistance of the bodies Ca and Ga, as found in table 3; from whence it appears that the said resistances are nearly the same; but, on considering the said bodies as ships at sea, and impelled forwards by the force of the wind in their sails; and by inspecting the above numbers it is found, that if the resistance of the bodies Ca and Ga be respectively equal to 1, that then the capacity and stability, or comparative power to carry sail, as also the vis insita force of the long body Ca would be 17·523, and of the short body Ga, 11·899.

From whence it is evident, that the long body Ca has not only the advantage of being capable of bearing about one-third more sail than the short body Ga, but it also has an advantage, arising from its great vis insita force, or the power of overcoming such resistance as may be occasioned by the undulation of the water (or otherwise) to its direct motion.

And further, it is to be considered, that the pitching motion is not so quick, nor the arcs of vibration in general so great, in long[1] ships, as in short ships; therefore the short ship has not only a disadvantage (as compared with a long ship), arising from the smallness of its vis insita force, but also the disadvantage of such vis insita force being destroyed in a much greater degree, by the pitching motion, than the vis insita force of the long ship possibly can, by its pitching motion.

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[1] This comparison alludes to ships of the same form and dimensions in the head end and stern end, and having the same form in the midship section; but of different lengths, by means of midship body: or to the advantages and disadvantages in ships that have been lengthened, as compared before and after they are lengthened in the midship body.

Again, it is also necessary to consider, that the power of the wind, by which ships obtain their velocity, is variable in its force and direction, in almost every instant of time. Consequently the long ship, which has the greatest vis insita force, will have the advantage as compared with the short ship, of moving with more uniformity in its velocity, and more steadiness in its direct motion; and will of course thereby feel the power of the wind upon its sails in a greater comparative degree, than the short ship can upon its sails.

In the experiments of the year 1796, it will be seen, by inspecting plate 6, that the bodies APa, EPa, KPa, LPa, were respectively constructed with differently formed head ends, but with the same middle part and stern end.

Then, for the sake of comparison, we shall place the resistance of the said bodies as ships moving with the velocity of five miles per hour (and as found in table 3) as numerators; and the capacities or weights of the said bodies, under their correspondent resistances as denominators; and as follows:

APa	Resistance =	*lb.* 23·48	EPa	Resistance =	*lb.* 28·26
	Capacity =	810·01		Capacity =	761·87
KPa	Resistance =	*lb.* 27·50	LPa	Resistance =	*lb.* 26·77
	Capacity =	805·62		Capacity =	833·12

By reducing the above numbers to their lowest terms, the relation which the resistance bears to the capacity, or the capacity to the resistance, will be as follows:

APa	EPa	KPa	LPa
$\frac{1}{34 \cdot 498}$	$\frac{1}{26 \cdot 959}$	$\frac{1}{29 \cdot 295}$	$\frac{1}{31 \cdot 098}$

Now, the body APa is exactly of the same form and dimensions in its head end and stern end, and in every respect, except in the length of its middle part, as the body Aa, (in the experiments of 1798.) But by comparing the relation which the resistance bears to the capacity, &c. of the body Aa, as already found in this chapter, with the relation which the re-

sistance bears to the capacity, &c. of the body APa, as found above, it appears, that if the resistance of the said bodies Aa, and APa, be respectively equal to one, that then the capacity and comparative stability, and vis insita force, of the short body Aa, would be 15·175; and of the long body APa, 34·498. From whence a very considerable advantage appears in favour of the long body APa, and which arises from the length of the midship body only[1].

The isosceles angular head end E, of the body EPa, and the projecting angular head end K, of the body KPa, were constructed so as to have the same angle of inclination, and the same area of oblique surface in their respective head ends; that is to say, that the hypothenuse, or oblique surface of the head end K, is equal to the sum of the two sides, or oblique surface of the head end E.

The oblique surface of the head end K, was made to incline upwards for the purpose of ascertaining the advantage or disadvantage which might arise from its resistance in such position, as compared with the resistance of the head end E, according to its position.

Now, by comparing the relation which the resistance bears to the capacity, &c. of the said bodies, as already given in this chapter, it appears, that if the resistance of the bodies EPa, and KPa, be respectively equal to one, then the capacity, or stability, or vis insita force, of EPa, is 26·959, and of KPa, 29·295, which shows an advantage in favour of the body KPa[2], that is of some moment, and which advantage arises from the form of its head end only.

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[1] In like manner comparisons may be made with the other bodies; and it is a method of reasoning which applies to all kinds of vessels moved by sails. But in applying the said method of reasoning to ships or models of differently formed midship sections, and of different breadths and depths, it is of course then necessary to ascertain the stability of each body, according to its particular form, and the height of its centre of gravity, &c. &c.

[2] This advantage is supposed to arise from the particles of water which strike the oblique surface of the said head end K, being deflected downwards under the body, by which means the head end is impelled upwards. We shall have occasion to make further observations on the advantages arising from projecting forms, when treating of the experiments near the surface of the water, in the second part of the Report.

The compound projecting angular head end L, of the body LPa, was constructed with the same angle of inclination upwards, in the direction of y r, (see plate 6, Experiments 1796,) as the head end K, of the body KPa, and the horizontal section of its pointed end is an equilateral triangle; this head end was constructed for the purpose of ascertaining the advantage or disadvantage which might arise from such form as compared with the head end K, of the body KPa.

Now, by comparing the relation which the resistance bears to the capacity, &c. of the said bodies, as already given in this chapter, it appears, that if the resistance of the bodies KPa, and LPa, be respectively equal to 1, then the capacity, or stability, or vis insita force, of the body KPa, is 29·295; and of the body LPa, 31·098, which gives an advantage in favour of the body LPa, and which advantage arises from the form of its head end only.

CHAP. V.—*On the finding the Plus and Minus Pressures (together and separately) of the different Bodies respectively, with comparative Observations respecting the Law of the Plus Pressure against Direct and Oblique Surfaces.*

THE motive powers requisite to overcome the plus and minus pressures (together) of the different bodies respectively, may be found in two ways: that is, either by deducting the friction of the water which takes place against the total surface of the different bodies as found in table 2, from the total resistance of the said bodies, as found in table 1, then the remaining numbers will be equal to the motive powers requisite to overcome the plus and minus pressures (together) of the different bodies respectively. Or by deducting the friction against the sides and bottom surface of the different bodies, as found in table 2, from the resistance of the said bodies, as ships, and as found in table 3, then the remaining numbers will also be equal to the motive powers requisite to overcome the plus and minus pressures (together) of the different bodies respectively. Of which two me-

thods we have used the latter one, and the plus and minus pressures (together) of the different bodies respectively, is thereby found in table 3.

Then, in order to separate the said plus and minus pressures, we shall first compare the resistance of the bodies Ao, and Aa, (plate 5,) as found in the columns of table 1, which are as follow:—

Nautical miles per hour =	1	2	3	4	5	6	7	8
Motive powers in pounds and part of pounds.								
	lb.	*lb.*	*lb.*	*lb.*	*lb.*	*lb.*	*lb.*	*lb.*
Body Ao....................	0·73	2·94	6·52	11·38	17·43	24·62	32·85	42·07
Body Aa....................	0·71	2·87	6·38	11·17	17·14	24·26	32·42	41·59

Now, by inspecting the form and dimensions of the said bodies, as found in plate 5, it will be seen, that the head end and middle part of the said bodies are the same, and that the said bodies only differ in the form and dimension of their stern ends. Consequently, whatever difference arises between the resistances of the said bodies, as found above, must be occasioned by the form and dimensions of the stern ends only. Then, by inspecting the above numbers, it appears that the body Ao meets with a little more resistance than the body Aa; which evidently shows that the stern resistance of the body Ao is a little more than the stern resistance of the body Aa.

And further, by comparing the total resistance of the body Ho, with the total resistance of the body Ha, as respectively found in the columns of table 1, they are as follow:—

Nautical miles per hour =	1	2	3	4	5	6	7	8
Motive powers in pounds, and decimal parts of pounds.								
	lb.	*lb.*	*lb.*	*lb.*	*lb.*	*lb.*	*lb.*	*lb.*
Body Ho....................	0·78	3·20	7·21	12·62	19·78	28·25	38·10	49·28
Body Ha....................	0·76	3·13	7·06	12·55	19·37	27·67	37·31	48·26

Now, in this comparison, the same result as the former is proved, namely, that the stern resistance of the body Ho, is a little more than the stern resistance of the body Ha[1].

But when the friction against the several surfaces of the bodies Ao, and Aa, is deducted (which is done in table 3,) then, by comparing the plus and minus pressures (together) of the said body Ao, with the plus and minus pressures (together) of the said body Aa, as found in table 3, they are as follows:—

Nautical miles per hour.... =	1	2	3	4	5	6	7	8
Plus and minus pressure (together) of Ao, as per table 3 .... =	0·40	1·79	4·19	7·57	11·92	17·25	23·50	30·67
Plus and minus pressure (together) of Aa, as per table 3 .... =	0·44	1·92	4·46	8·01	12·56	18·14	24·66	32·13

Now, according to the above numbers, it appears that the plus and minus pressures (together) of the body Ao, is a little less than the plus and minus pressures (together) of the body Aa.

But as the plus pressure against the head end A, must be the same in both bodies, and as the friction is wholly taken away, therefore the difference between the said numbers must be the difference of the minus pressure only; which difference being very small, when compared with the great difference in the length of the stern ends o, and a, thence it may fairly be inferred, that the stern end o, has no minus pressure; or, if any, that it is so small as to be of no moment in the present investigation of the subject.

Then, taking the minus pressure of the stern end o, of the body Ao, to be equal to 0·000lb., at any velocity from 1 to 8 nautical miles per hour; from thence the plus pressures and minus pressures, to all the other bodies, are separately found, as in table 3.

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[1] This is a curious fact, and very interesting to the constructors of ships.

Comparative Observation respecting the Law of the Plus Pressure against Direct and Oblique Surfaces.

Now, if we take the plus pressure of the flat head end I, of the body Io, at the velocity of 8 miles per hour, as found in table 3, and which is equal to 148·25lb., and reduce it according to the sines of the angles of incidence of the different angular head ends A, D, E, F, such plus pressures will come out as in this table:

Angle of incidence.	Plus pressure by experiment.	Plus pressure by theory sine of angle of incidence to radius 148·25lb.
° ′ ″	*lb.*	*lb.*
A = 9·44·10	= 30·67	24·71
D = 14·28·40	35·34	37·06
E = 19·28·15	41·71	49·42
F = 30·00·00	51·44	74·13

And by comparing the said plus pressures with the plus pressure, as deduced from experiment with the said bodies, as found in table 3, and as also found in the above table; from thence it is evident, that the plus pressures, as deduced from experiment, do not follow the law of the sine of the angle of incidence, nor any regular law that we have yet discovered.

Chap. VI.—*Tables of the Law, or Indexes of the Power of the Velocity, by which the total Resistance—the Friction—the Plus Pressure—and the Minus Pressure of the different Bodies respectively increase, or decrease, with Observations thereon.*

TABLE I.

Indexes of the Power of the Velocity, by which the total Resistance of the different Bodies increase or decrease.

Nautical miles per hour.... =			2	3	4	5	6	7	8
			Indexes of the power of the velocity.						
This Table is formed by comparing the resistance of the different bodies at the velocity of 1 mile per hour (as found in the second or under line of figures that are opposite to each body in the left hand columns of table 1 of the experiments, see page 385,) with the resistance at each of the following velocities up to 8 miles per hour; and by the method specified in chapter 2, example 1.	Bodies used in the experiments of the year 1798.	Ao	2·010	1·993	1·981	1·971	1·964	1·956	1·950
		Aa	2·015	1·999	1·988	1·978	1·971	1·964	1·958
		Ab	2·042	2·030	2·020	2·013	2·007	2·001	1·996
		Ac	2·000	1·983	1·971	1·962	1·954	1·946	1·940
		Ad	1·987	1·973	1·961	1·951	1·942	1·934	1·927
		Ae	2·034	2·019	2·011	2·003	1·998	1·992	1·987
		Af	2·053	2·045	2·041	2·036	2·033	2·030	2·027
		Ag	1·965	1·950	1·938	1·928	1·919	1·911	1·904
		Ah	2·020	2·006	2·996	1·988	1·982	1·976	1·971
		Ai	2·027	2·014	2·006	2·000	1·995	1·990	1·985
		Ba	2·040	2·030	2·021	2·014	2·009	2·004	1·999
		Ca	2·005	1·991	1·980	1·971	1·963	1·956	1·950
		Da	2·014	2·001	1·993	1·986	1·980	1·974	1·969
		Ea	2·026	2·012	2·003	1·995	1·989	1·983	1·977
		Fa	2·019	2·010	2·002	1·996	1·991	1·986	1·981
		Ga	2·038	2·027	2·020	2·014	2·008	2·004	1·999
		Ha	2·042	2·029	2·019	2·012	2·006	2·001	1·996
		Ho	2·037	2·024	2·016	2·009	2·003	1·998	1·994
		Ia	2·018	2·011	2·006	2·002	1·999	1·996	1·994
		Io	2·012	2·006	2·002	1·998	1·995	1·992	1·989
	Bodies used in the experiments of the year 1796.	APa	1.822	1·818	1·817	1·816	1·816	1·815	1·815
		EPa	1.839	1·833	1·831	1·831	1·830	1·829	1·829
		KPa	1.853	1·849	1·849	1·846	1·848	1·848	1·847
		LPa	1.847	1·842	1·841	1·840	1·839	1·838	1·838
		IPa	1.954	1·952	1·952	1·951	1·951	1·951	1·951
		APe	1.833	1·832	1·831	1·831	1·831	1·830	1·830
		APk	1.861	1·856	1·855	1·854	1·854	1·853	1·853
		APj	1.818	1·817	1·817	1·816	1·816	1·815	1·815
		APi	1.873	1·869	1·868	1·868	1·867	1·867	1·867

Observations.—By inspecting the numbers in this table 1, it appears, that the power of the velocity of the bodies used in

the experiments of the year 1798, at 2 miles per hour, is, in general, a little above the duplicate ratio, or square of the velocity; but that the ratio gradually decreases as the velocity increases, and becomes a little less than the duplicate ratio at the velocity of 8 miles per hour (except with the body Af, which is always greater than the duplicate ratio.)

And, with respect to the bodies used in the year 1796, it also appears, by inspecting the numbers in this table 1, that the power of the velocity, with the said bodies, is considerably less than that of the bodies used in 1798, and is always less than the duplicate ratio. This difference in the power of the velocity of 1798 and 1796, arises from the bodies used in 1796 having a much greater surface for friction than the bodies used in 1798; and also because the said friction always increases in a much less ratio than the duplicate ratio. (See table 2, of this chapter, below.) So that the friction of the bodies used in 1796 forms a greater proportional part of their total resistance, than it does in the bodies used in 1798.

TABLE II.

Indexes of the Power of the Velocity by which the Resistance, arising from the Friction of the Water increases or decreases.

Nautical miles per hour .... =		2	3	4	5	6	7	8
		Indexes of the power of the velocity.						
This table is formed by comparing the friction on 46 square feet of surface, as found by the experiments of 1798; and also by comparing the friction on 50 square feet of surface, as found by the experiments of 1796, according to the method specified for table 1, in this chapter.	From the friction as found by the experiments of the year 1798.	1·823	1·800	1·780	1·762	1·745	1·729	1·713
	From the friction as found by the experiments of the year 1796.	1·753	1·741	1·734	1·729	1·726	1·723	1·720

TABLE III.

Indexes of the Power of the Velocity by which the Plus Pressures of the different Bodies increase or decrease.

Nautical miles per hour .... =			2	3	4	5	6	7	8
			Indexes of the power of the velocity.						
This table is formed by comparing the plus pressures of the different bodies (as found in table 3) according to the method specified, as for table 1, in this chapter.	Head ends of the bodies used in the year 1798.	A	2·162	2·138	2·121	2·109	2·101	2·093	2·087
		B	2·219	2·201	2·192	2·184	2·179	2·173	2·168
		C	2·136	2·119	2·106	2·096	2·088	2·080	2·074
		D	2·116	2·098	2·092	2·086	2·078	2·072	2·067
		E	2·108	2·090	2·081	2·073	2·067	2·061	2·056
		F	2·091	2·078	2·069	2·062	2·056	2·051	2·046
		G	2·162	2·140	2·132	2·125	2·118	2·113	2·109
		H	2·142	2·120	2·107	2·099	2·092	2·087	2·082
		I	2·036	2·029	2·024	2·020	2·017	2·014	2·012
	Head ends of the bodies used in the year 1796.	A	2·162	2·138	2·121	2·109	2·101	2·093	2·087
		E	2·068	2·050	2·038	2·029	2·023	2·019	2·014
		K	2·155	2·132	2·118	2·106	2·098	2·092	2·086
		L	2·158	2·135	2·119	2·105	2·096	2·090	2·084
		I	2·068	2·059	2·053	2·048	2·045	2·043	2·041

Observation.—By inspecting the numbers in this table 3, it appears that the power of the velocity of the plus pressure is always above the duplicate ratio.

TABLE IV.

Indexes of the Power of the Velocity by which the Minus Pressures of the different Bodies increase or decrease.

Nautical miles per hour.... =			2	3	4	5	6	7	8
			Indexes of the power of the velocity.						
This table is formed by comparing the minus pressures of the different bodies (as found in table 3 of Analysis) according to the method specified, as for table 1, in this chapter.	Stern ends of the bodies used in the year 1798.	a	1·701	1·738	1·730	1·723	1·731	1·730	1·730
		b	——	——	5·416	4·823	4·426	4·205	4·053
		c	1·837	1·834	1·834	1·830	1·820	1·813	1·806
		d	1·751	1·744	1·740	1·729	1·714	1·698	1·682
		e	1·968	1·964	1·976	1·980	1·982	1·982	1·982
		f	2·060	2·061	2·065	2·066	2·066	2·066	2·066
		g	1·860	1·841	1·828	1·818	1·806	1·795	1·785
		h	1·953	1·939	1·936	1·933	1·930	1·927	1·924
		i	1·978	1·969	1·969	1·967	1·965	1·963	1·961

Observation on Table IV.—By inspecting the numbers in this table 4, it appears, that the power of the velocity of the minus pressure is various, and is always less than the duplicate ratio, except with the stern ends b and f, which is always greater than the duplicate ratio. Now, as the minus pressure of the stern end b is very little, only 0·04lb. at the velocity of 3 miles per hour, and 2·13lb. at 8 miles per hour, (see the body Ab in table 3, page 398,) therefore the great comparative ratio by which the said minus pressure increases, might partly arise from the form of the stern end, and partly from a small error in the experiments with the said body, at the slow velocities; for an error of one-twelfth part of a pound in the resistance, at the velocity of 1 mile per hour, would produce the effect in the law of the minus pressure, as shown in this table.

Chap. VII.—*Comparative Observations respecting the Resistance of the Isosceles Triangle, the Cube, the Square, the Plane, the Round Plane, the Cylinder, the Globe, &c., as used in the Experiments of the Year* 1797, *wherein the Effect of the Deflection of the Water on the Minus Pressure is exemplified; with Comparisons relative to the Accuracy of the Experiments.*

The isosceles triangle M, in the experiments of the year 1797, is exactly of the same form and dimensions as the angular head end A of the body Ai, &c. in the experiments of the year 1798. (See plates 5 and 6.) From whence the plus pressure of the said triangle M, is conceived to be the same as the plus pressure of the said head end A, and the minus pressure of M, is conceived to be nearly the same as the minus pressure of the stern end i, and the friction on M being given in table 2. Then, for the sake of comparison, we shall compare the sum of these resistances with the total resistance of the triangle M, as found by actual experiment in table 1, page 388, as follows:

Nautical miles per hour =	1	2	3	4	5	6	7	8
	Motive powers in pounds and decimal parts.							
	lb.	*lb.*	*lb.*	*lb.*	*lb.*	*lb.*	*lb.*	*lb.*
Plus pressure of A, table 3, page 401, experiments, 1798	0 ·40	1 ·79	4 ·19	7 ·57	11 ·92	17 ·25	23 ·50	30 ·67
Minus pressure of i, table 3, page 402, experiments, 1798	0 ·49	1 ·93	4 ·26	7 ·51	11 ·62	16 ·57	22 ·35	28 ·92
Friction on M, table 2, experiments, 1798....	0 ·11	0 ·39	0 ·79	1 ·29	1 ·87	2 ·50	3 ·17	3 ·87
This sum for the total resistance of triangle M	1 ·00	4 ·11	9 ·24	16 ·37	25 ·41	36 ·32	49 ·02	63 ·46
The total resistance of triangle M, by actual experiment, as found in table 1 page 388 ..	1 ·12	4 ·39	9 ·70	16 ·96	26 ·13	37 ·15	49 ·99	64 ·61

By inspecting these numbers, it appears, that the total resistance of the triangle M, as found by actual experiment in 1797, is a little more than the total resistance as deduced from the experiments of 1798.

This small[1] difference is conceived to arise from the effect which the deflection of the water has on the minus pressure of the triangle M; for the water which is deflected by the oblique surface, or sides of the said triangle M, acts with its deflected force, to prevent the surrounding water from filling up the void at the base or stern end of the triangle.

Whereas, in the body Ai, the water which is deflected by its oblique surface has time to lose the effect of deflection, and becomes parallel to the sides of the moving body before it arrives at its stern end; therefore the surrounding water is not impeded by deflection, from acting with its full force and pressure to fill up the void behind.

The cube R, the square iron plane S, the round iron plane

[1] It is necessary to observe, that the effect which the deflection has on the minus pressure of the triangle M, cannot be much, because its angular form is very acute.

T, and cylinder U, were constructed with the same area of flat surface, in the head end and stern end, namely, 1 square foot of surface in each, for the purpose of ascertaining the advantages or disadvantages, arising from such form, with respect to the effect of the deflection of the water.

By inspecting the resistances of the said bodies, as found in table 1, page 388, it appears that the cube R has less resistance than the square plane S; and that the cylinder U has less resistance than the round plane T; these differences evidently arise from the water, which is deflected by the front of the square plane S (and the same with respect to the round plane T) acting with its whole deflected force, to prevent the surrounding water from filling up the void behind.

Whereas, in the cube R[1], and cylinder U, the water which is deflected by the front of the said bodies, has time to lose a great part of its deflected force before it arrives at the stern end of the moving bodies, and, therefore, the surrounding water is but little impeded by deflection from filling up the void behind the said bodies R and U, respectively.

The experiments with the cylinder with a semi-globe for the stern end, called W, and the cylinder with a semi-globe for head end, called X, serve to show the advantages or disadvantages arising from such forms, and which may readily be seen by inspecting the resistances of the said bodies as found in table 1, page 388.

The cylinder with the semi-globe for head end, and stern end, called Y, and the globe Z, were constructed for the particular purpose of ascertaining the advantages or disadvantages arising from such forms, with respect to the effect of the deflection of the water.

Now, by inspecting the resistance of the said bodies, as found in table 1, page 388, we find that the resistance of the cylinder

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1 We apprehend that the difference which appears between the resistance of the cube R, and the cylinder U, arose from our not being able to draw the cube through the water with the same degree of steadiness as the cylinder; and it may be proper to observe, that we found great difficulty in drawing these short bodies, with flat head ends and flat stern ends, through the water with the same degree of steadiness as the other bodies, but the cube was the worst of all.

with a semi-globe on each end, or body Y, when moving at the velocity of 8 miles per hour, is 46·29lb., and that the resistance of the globe Z, at the same velocity, is 64·87lb., from whence it appears that there is a considerable advantage in favour of the body Y. This advantage evidently arises from the minus pressure of the body Y being very little, if at all, affected by the deflection of the water from its head end; because the water which is deflected by the circular surface of its head end has sufficient time to lose the effect of deflection, and becomes parallel to the sides of the moving body, before it arrives at the stern end; and, therefore, the surrounding water is not impeded by deflection from acting with its full force and pressure (or nearly so) to fill up the void behind.

Whereas, in the globe Z, the water which is deflected by the circular surface of its head end, acts with great force to prevent the surrounding water from filling up the void behind.

So that the comparative effect, arising from deflection alone, upon the minus pressure of the globe Z, appears to be 18·58lb. more than upon the body Y, which is very considerable.

Comparisons relative to the Accuracy of the Experiments.

The parallelopiped, or body IPi, in the experiments of the year 1796, was constructed for the purpose of making comparisons, or for verification, with respect to the accuracy of the experiments, as shown in the following example:

Nautical miles per hour=	1	2	3	4	5	6	7	8
	Motive powers in pounds and decimal parts.							
Plus pressure I, of the body IPa, table 3, page 404	2·14	8·97	20·54	36·83	57·81	83·51	113·94	148·98
Minus pressure i, of the body APi, table 3, page 405	0·69	2·42	5·04	8·56	12·96	18·16	24·24	31·15
Friction on total surface of IPi, table 2, page 395	0·56	1·89	3·79	6·20	9·06	12·34	16·01	20·03
Sum for the total resistance of body IPi =	3·39	13·28	29·37	51·59	79·83	114·01	154·19	200·16
Total resistance of body IPi, per actual experiment, table 1, page 390	3·39	13·19	29·14	51·16	79·16	113·08	152·86	198·47

By inspecting the above numbers, it appears, that the resistance of the body IPi, as deduced from the experiments, with the bodies IPa, and APi, comes out nearly the same as the resistance found by actual experiment with the said body IPi; and that the difference or deviation does not amount to $\frac{1}{120}$ part of the resistance; which is a strong proof of the accuracy of the experiments with the said bodies IPa, APi, and IPi, and which is further proved by comparing the plus pressure of the flat head end I, as found by the experiments of 1798, (table 3, page 401,) with the plus pressure of the flat head end I, as found by the experiments of 1796, (table 3, page 404,) as below:

Nautical miles per hour =	1	2	3	4	5	6	7	8
	Motive powers in pounds and parts.							
Plus pressure of I, as per body Ia, experiments, 1798	2·27	9·31	21·08	37·55	58·64	84·27	114·38	148·92
Plus pressure of I, as per body IPa, experiments, 1796	2·14	8·97	20·54	36·83	57·81	83·51	113·94	148·98

Chap. VIII.—*Comparative Observations respecting the Resistance arising from the Friction of the Water.*

It may be necessary to observe, for the sake of explaining the different effects which have been found with respect to friction, that the respective friction planks, and other bodies that were used in the experiments of the year 1796, were planed smooth and painted; *and that they were immersed a sufficient time in the water, so as to be pretty much water soaken,* (though clean from slime or dirt,) before the experiments were made.

And also, that the respective friction planks, and other bodies that were used in the experiments of the year 1798, were planed smooth and painted, *but were not water soaken;* and also clean from slime or dirt. (See table 2, on friction.)

From whence it is evident, that the experiments of the year 1798 were not made precisely under the same circumstances as the experiments of the year 1796; that is, so far as relates to the resistance arising from the friction; for it is to be noticed, that when bodies have been immersed some time in the water, so as to be pretty much water soaken, then the fibres of the wood start, and the surface becomes rougher than when such bodies were first immersed; therefore the resistance arising from the friction will be greater against the bodies that have been water soaken, as in the friction found by the experiments of 1796; and which is proved to be the case by the following comparison:

Nautical miles per hour =	1	2	3	4	5	6	7	8
	Motive powers in pounds and decimal parts of pounds.							
	lb.	*lb.*	*lb.*	*lb.*	*lb.*	*lb.*	*lb.*	*lb.*
Friction against 1 square foot of surface per experiments, 1796,.....	0·014	0·047	0·095	0. 155	0·266	0·309	0·400	0·501
Friction against 1 square foot of surface per experiments, 1798,.....	0·012	0·043	0·080	0·144	0·209	0·279	0·354	0·432

Now, as we had several opportunities of observing that there was a material difference between the resistance of the bodies when drawn through the water, both before and after they were water soaken, and that they always met with more resistance after they were water soaken, we have, therefore, not the smallest doubt but the difference in the friction, as found above, arises from the aforesaid cause.

And it may be useful to observe, that we have occasionally drawn bodies through the water that have been immersed long enough to gather a little slime on them, and have immediately afterwards drawn the same bodies through the water, by means of the same motive power, with the slime washed off, from whence we have always found that the bodies came the faster when the slime had been washed off.

Upon considering the results of the various experiments that

we have made respecting the effect of the friction of the water on moving bodies; it is evident to us, that the resistance arising from the friction (even against very smooth surfaces) is considerably more than it has generally been conceived to be, or than has hitherto been accounted for, in the estimation of the resistance which bodies meet with in moving through water at different velocities. And from whence it naturally follows, that, although ships may be built ever so much alike in their form and dimensions, yet still a very little difference in the smoothness of their bottoms (or in putting on the copper in coppered ships) will produce a considerable difference in their resistances, and, of course, in the comparative rate of their sailing.

CHAP. IX.—*Description of the Apparatus.*

THE apparatus consists of a three-legged stand, the legs of which are each about 60 feet in length, and 1 foot 6 inches square, and connected at the top by a 3-inch bolt, from which are hung four bolts, having an eye at each of their ends, through the lower of which passes a 3-inch bar, for the purpose of appending six blocks, that correspond to five similar blocks, fastened to a bar, upon which chains are fixed to suspend the box, made to contain the weights which may be necessary to draw the experimental body through the water. The eleven blocks just mentioned have each a brass shiver, of 13 inches diameter, with a steel pin fastened in the middle of the shiver, so that both the shiver and pin revolve together, by which means the shiver is prevented from ever touching the cheeks of the block: the ends of the pins work on Mr. Garnett's patent rollers, fitted in containers, made spherical, so that they may move freely, in order always to insure the pin a fair bearing on the rollers. A four-strand rope, of an inch diameter, made of the best hemp, is reeved through the blocks in such a manner that the standing and running parts go first through the middle blocks, by which means the box of weights is always kept

horizontal. The running part of the rope, which comes down from the above-mentioned blocks, passes under a vertical wheel, of 14 feet circumference, the frame of which is fastened to the ground, and from thence, horizontally, to the body on trial. The standing part of the rope passes round the barrel of a crab, by which a horse winds up the box of weights. The running part of the rope leads immediately from the vertical wheel to the floating body on trial; and the tension of the rope, that is, the actual power employed to give the body the velocity required, has been as repeatedly ascertained as any alteration of circumstances rendered such examinations requisite: by calculation it is evident the tension, independent of friction, must have been always equal to $\frac{1}{10}$ of the weight of the box, bolts, lower blocks, chains, &c., for the power is to the weight as units to twice the number of moveable blocks.

The friction of the ropes, pullies, &c., was determined in the following manner:—Weight was gradually fastened to the fall, or running part of the rope, till it became just sufficient to make the box of weights ascend gently. This done, the counterpoise, which was fastened to the running end of the rope, was gradually diminished, until the box began to descend gently. Then the half of the difference of those two weights, viz., of that which was little more, and of that which was little less, than sufficient to counterbalance the box of weights, was considered as the obstruction occasioned by the friction of blocks, rope, &c.; and when the body under trial did not, from its form, preserve a direct course, a thin piece of board, about four feet long, and eight inches wide, was applied as a rudder, which produced the desired effect, at the same time that it added very little to the friction in the water. And in order to measure the velocity of the body on trial, on the axis of the vertical wheel, there is a groove, or swage, to receive a thin silk line, leading from thence round two small brass pullies to a cylinder, placed horizontally, which partakes, by means of that line, of the motion of the wheel upon the surface of the cylinder. A spiral groove is turned, in order to receive another small silk line, that is fastened to a thin fir batten, sliding in a groove in the scale made on the edge of a long deal board, on which edge the scale is graduated by actual admeasurement, so

that the sliding batten moves one inch for every foot run through by the body on trial: and near the end of the scale a machine, worked by a pendulum, is so contrived as to cause, by a spring, a pencil to leave a mark on the sliding batten at the end of every two, three, or, indeed, at the end of any number of seconds, according as the machine is set; of course, therefore, the space described in those times, by the body on trial, must be accurately shown by the respective distances of the pencil marks from each other on the batten.

It having been observed that the body, in the beginning of its motion, went at a much slower rate than the velocity which it acquired afterwards, and which continued nearly for the remainder of its course, it was thought necessary to increase the moving power in the beginning only, so as to enable the body to acquire that uniform velocity much sooner; and this was effected in the following manner:—An iron ball, weighing about 1800lb., was suspended to the box, at some distance below it, by means of a long rope, so that the body, in the beginning of the motion, was acted upon by both the weights of the box and of the iron ball; but as the ball came to the ground much sooner than the box, its action was of course suspended after a certain period; and, for the sake of accuracy, even the long rope which supported the iron ball was, by means of a particular contrivance, discharged from the box the moment in which the iron ball touched the ground.

Improvements and Alterations made in the Apparatus, previous to the Experiments in the Years 1796, 1797, *and* 1798.

The scale, instead of being at right angles to the wheel under which the rope passed, was placed parallel to it, and the cylinder (which in these experiments was larger than that used before) was fixed to the arbor of the wheel by an iron axis, and the helix was square instead of triangular.

To keep the silk line which drew the batten, or thin piece of wood on which the pencil marked, always of an equal tension, we placed, at the end of the trough in which the batten slid, a double cylinder, bearing a proportion to each other nearly as one to seven; round each of these cylinders a silk line was

wound; the end of that on the larger was fastened to the hind part of the batten, and to that on the smaller cylinder a four pound weight was hung; this was called the retarding weight, and was designed to correct the irregularity which we had sometimes remarked, during our former experiments, in the movement of the batten, when its progress was obstructed by sand or any other small substance[1].

The scale was graduated by the following method:—A piece of wire was wound round the periphery of the large wheel[2] once, and fourteen times in the helix of the cylinder; the first wire was found to measure 13 feet 10·7 inches, the second 19 feet 11·9 inches; consequently, one revolution was 1 foot 5·1357 inches; then, by the annexed proportion, will be found the space on the scale answering to 14 feet.

As 13. 10·7 (ft. in.) : 1. 5·1357 (ft. in.) :: 14 (ft.) : 1. 5·269 (ft. in.), the space on the scale to be divided into 14 equal parts.

A certain number of divisions, each equal to 1 foot 5·269 inches, were then set off along the scale with a pair of beam compasses; these divisions were again divided into 14 equal parts, and each fourteenth into 10, and the parts of this last division were still large enough to be divided by the eye into tenths; thus each foot may be said to contain 100 divisions; consequently, when the moving body was drawn with a celerity of 10 feet per second, this small portion of time was accurately divided into 1000 equal parts.

The silk twist, intended to draw the batten, was wound fourteen times in the helix of the cylinder, and being measured, gave 19 feet 11·33 inches; whereas the wire gave 19 feet 11·9 inches; consequently, to correct the error arising from the difference of size between the silk and wire, the feet, and decimal parts of a foot, read off the scale, must be multiplied by 239·9, and divided by 239·33.

Four different-sized lines were used to draw the bodies

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[1] The trough not being sufficiently elevated above the ground, the line attached to the small cylinder, passed through a small brass pully, to which was hung an 8lb. weight.

[2] This wheel was made so light that we found, from repeated observations, that no error arose in the experiments from its acting as a fly.

through the water. No. 1, or the largest, measured, in diameter, 0·355 parts of an inch; No. 2, 0·237; No. 3, 0·185; No. 4, 0·041, or the same size as the wire; here, likewise, a second correction must be made for the semi-diameter of the lines above that of the wire; and, after the first correction has been applied, the result, where line 1 is used, must be multiplied by 167·6807, and divided by 166·7, or increase the divisions by $\frac{59}{10000}$ parts of the whole, and the same result is obtained; when line 2 is used, the divisions, after the first correction, must be increased by $\frac{37}{10000}$ of the whole, line 3 by $\frac{27}{10000}$, but line 4 requires no other correction than that made for the excess of the thickness of the wire above the silk line, which is $\frac{24}{10000}$ of the number of divisions read off the scale.

Previous to these experiments, the clock was regulated by an accurate astronomical time-piece, keeping mean time; and to prevent any accidental alteration in the pendulum, the bob and rod were connected finely together by a screw. By a simple contrivance, the pendulum was drawn as much from a perpendicular as was equal to half its arch of vibration, and then suddenly let go on the body's commencing its motion.

It may not be improper to mention that, in these experiments, a chain[1] was used for an accelerating weight, the former mode of hanging on a given number of pounds being found to give the line which drew the body a tremulous motion, on the weights suddenly coming to the ground; the gradual diminution of the chain's weight effectually removed this inconvenience.

The bodies were respectively fixed to the conductor bars, (Plates 5 and 6), and immersed to the medium depth of six feet under the surface of the water; the conductor then swam with its top surface exactly one inch above the surface of the water.

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[1] The length of the chain was 12 feet 6 inches.

TABLE I.

Motive Powers requisite to overcome the Resistances of the several Bodies used in the Experiments of the Year 1798, *when they were moved at Velocities in Nautical Miles, per Hour, as expressed underneath.*

	Nautical miles per hour.							
	8	7	6	5	4	3	2	1
	Motive powers in pounds.							
Conductor and bar only	142·57	105·07	73·86	48·69	29·23	15·14	5·99	1·23
Conductor bar & long friction plank	212·618	160·502	116·006	79·019	49·389	26·947	11·472	2·665
Long friction plank alone	70·048	55·432	42·146	30·329	20·159	11·807	5·482	1·435
Conductor bar & short friction plk.	192·762	144·215	103·167	69·421	42·747	22·879	9·480	2·102
Short friction plank alone	50·192	39·145	29·307	20·731	13·517	7·739	3·490	0·872
Conductor bar and body Ao	184·16	137·92	98·48	66·12	40·61	21·66	8·33	1·96
Body Ao alone	42·07	32·85	24·62	17·43	11·38	6·52	2·94	0·73
Conductor bar and Aa	184·64	137·49	98·12	65·83	40·40	21·52	8·86	1·94
Body Aa alone	41·59	32·42	24·26	17·14	11·17	6·38	2·87	0·71
Conductor bar and Ab	185·10	137·96	98·26	65·78	40·25	21·37	8·75	1·90
Body Ab alone	42·53	32·89	24·40	17·09	11·02	6·23	2·76	0·67
Conductor bar and Ac	189·43	141·71	101·36	68·20	41·99	22·47	9·31	2·06
Body Ac alone	46·86	36·64	27·50	19·51	12·76	7·33	3·32	0·83
Conductor bar and Ad	187·68	140·43	100·48	67·62	41·65	22·30	9·24	2·05
Body Ad alone	45·11	35·36	26·62	18·93	12·42	7·16	3·25	0·82
Conductor bar and Ae	194·94	146·61	103·97	69·81	42·87	22·86	9·43	2·07
Body Ae alone	52·37	40·54	30·11	21·12	13·64	7·72	3·44	0·84
Conductor bar and Af	219·01	163·72	117·00	78·64	48·36	25·83	10·68	2·36
Body Af alone	76·44	58·65	43·14	29·95	19·13	10·69	4·69	1·13
Conductor bar and Ag	202·34	152·09	109·38	74·07	45·96	24·85	10·44	2·37
Body Ag alone	59·77	47·02	35·52	25·38	16·73	9·71	4·45	1·14
Conductor bar and Ah	196·77	147·16	105·23	70·77	43·55	23·29	9·64	2·13
Body Ah alone	54·20	42·09	31·37	22·08	14·32	8·15	3·65	0·90
Conductor bar and Ai	207·75	155·51	111·30	74·94	46·18	24·74	10·27	2·28
Body Ai alone	65·18	50·44	37·44	26·25	16·95	9·60	4·28	1·05
Conductor bar and Ba	182·79	136·15	96·90	64·81	39·61	21·00	8·58	1·86
Body Ba alone	40·22	31·08	23·04	16·12	10·38	5·86	2·59	0·63
Conductor bar and Ca	186·36	139·24	99·46	66·81	41·05	21·91	9·04	1·99
Body Ca alone	43·79	34·17	25·60	18·12	11·82	6·77	3·05	0·76
Conductor bar and Da	187·53	140·00	99·90	67·02	41·12	21·90	9·02	1·98
Body Da alone	44·96	34·93	26·04	18·33	11·89	6·76	3·03	0·75
Conductor bar and Ea	193·25	144·39	103·13	69·27	42·56	22·71	9·37	2·06
Body Ea alone	50·68	39·32	29·27	20·58	13·33	7·57	3·38	0·83
Conductor bar and Fa	202·30	151·32	108·22	72·79	44·80	23·97	9·92	2·20
Body Fa alone	59·73	46·25	34·36	24·10	15·57	8·83	3·93	0·97
Conducter bar and Ga	184·74	137·64	97·98	65·56	40·09	21·26	8·70	1·89
Body Ga alone	42·17	32·57	24·12	16·87	10·86	6·12	2·71	0·66
Conductor bar and Ha	190·83	142·38	101·53	68·06	41·72	22·20	9·12	1·99
Body Ha alone	48·26	37·31	27·67	19·37	12·49	7·06	3·13	0·76
Conductor bar and Ho	191·85	143·17	102·11	68·47	41·99	22·35	9·19	2·01
Body Ho alone	49·28	38·10	28·25	19·78	12·76	7·21	3·20	0·78
Conductor bar and Ia	298·54	225·20	162·64	110·68	69·09	37·64	15·99	3·70
Body Ia alone	155·97	120·13	88·78	61·99	39·86	22·50	10·00	2·47
Conductor bar and Io	298·35	225·13	162·64	110·17	69·16	37·70	16·03	3·72
Body Io alone	155·78	120·06	88·78	62·02	39·93	22·56	10·04	2·49

Note.—Deduct the resistance of the conductor and bar, as given in the top line, from that of the conductor bar, and respective body, the remainder will be the resistance of the body alone.

A continuation of Table 1.

Velocities of the several Bodies used in the Year 1798, *as obtained by Experiment; and also as brought into a regular Series, by the Method specified in Chapter* 2.

	Motive powers in pounds avoirdupois.								Power of the Velocity.
	12	24	36	48	60	72	96	120	
	Velocities, in feet, per second.								
Conductor and bar, by experiment	4·568	6·183	7·399	8·342	.....	10·033	......	......	2·2860
By series	4·582	6·205	7·409	8·402	9·264	10·033	11·378	12·545	
[1] Long friction plank, by experiment	3·408	4·888	5·847	6·668	7·420	8·161	9·327	10·310	2·1060
By series	3·455	4·801	5·821	6·673	7·419	8·090	9·273	10·310	
Short friction plank, by experiment	3·739	5·262	6·308	7·136	7·917	8·599	9·815	10·953	2·1779
By series	3·770	5·186	6·250	7·134	7·906	8·598	9·815	10·877	
Body Ao, by experiment	3·828	5·376	.....	7·353	.....	8·770	10·028	......	2·1849
By series	3·872	5·317	6·401	7·302	8·087	8·791	10·028	11·106	
Body Aa, by experiment	3·833	5·380	6·458	7·334	.....	8·808	10·045	......	2·1886
By series	3·884	5·332	6·417	7·318	8·104	8·808	10·045	11·123	
Body Ab, by experiment	3·900	5·371	.....	7·307	.....	8·814	10·039	......	2·2014
By series	3·903	5·348	6·430	7·327	8·109	8·809	10·039	11·110	
Body Ac, by experiment	.....	5·214	.....	7·166	.....	8·684	9·895	......	2·1736
By series	3·801	5·229	6·302	7·193	7·971	8·668	9·895	10·965	
Body Ad, by experiment	3·797	5·289	.....	7·227	.....	8·736	9·935	......	2·1719
By series	3·814	5·248	6·325	7·221	8·002	8·702	9·935	11·010	

[1] The long and short friction planks are of the same degree of smoothness, and the ends of both are semicircular. The long friction plank contains 46 square feet more surface than the short.

A continuation of Table 1.

	Velocities, in feet, per second.								Power of the Velocity.
Body Ae, by experiment	3·729	5·222	.....	7·220	.....	8·592	9·782	......	2·1850
By series	3·777	5·187	6·244	7·123	7·889	8·575	9·782	10·834	
Body Af, by experiment	.....	4·898	.....	6·750	.....	8·141	9·265	......	2·1792
By series	3·568	4·904	5·997	6·741	7·468	8·119	9·265	10·264	
Body Ag, by experiment	3·588	5·009	.....	6·917	.....	8·341	9·545	......	2·1383
By series	3·610	4·991	6·034	6·902	7·662	8·344	9·545	10·595	
Body Ah, by experiment	3·707	5·223	6·234	7·076	7·867	8·522	9·758	......	2·1757
By series	3·740	5·143	6·197	7·073	7·837	8·522	9·727	10·777	
Body Ai, by experiment	3·596	5·058	.....	6·935	.....	8·315	9·477	......	2·1694
By series	3·634	5·002	6·030	6·885	7·631	8·301	0·477	10·503	
Body Ba, by experiment	3·920	5·431	.....	7·367	.....	8·835	10·103	......	2·2061
By series	3·936	5·390	6·477	7·379	8·164	8·868	10·103	11·178	
Body Ca, by experiment	.....	5·306	.....	7·234	.....	8·751	9·982	......	2·1825
By series	3·850	5·289	6·369	7·266	8·048	8·749	9·982	11·057	
Body Da, by experiment	3·827	5·344	.....	7·277	.....	8·751	9·963	......	2·1893
By series	3·854	5·289	6·365	7·259	8·038	8·736	9·963	11·032	
Body Ea, by experiment	3·751	5·231	.....	7·224	.....	8·614	9·818	......	2·1829
By series	3·787	5·203	6·264	7·147	7·916	8·606	9·818	10·875	
Body Fa, by experiment	.....	5·061	.....	7·005	.....	8·440	9·602	......	2·1748
By series	3·691	5·076	6·116	6·981	7·736	8·412	9·602	10·639	
Body Ga, by experiment	.....	5·352	.....	7·351	.....	8·831	10·052	......	2·2044
By series	3·914	5·360	6·442	7·340	8·122	8·822	10·052	11·123	
Body Ha, by experiment	3·774	.....	6·375	7·223	8·065	8·714	9·890	......	2·1935
By series	3·833	5·257	6·324	7·210	7·983	8·674	9·890	10·949	
Body Ho, by experiment	3·726	5·255	6·351	7·212	7·936	8·620	9·802	10·921	2·1920
By series	3·820	5·241	6·306	7·190	7·960	8·651	9·864	10·921	
Body Ia, by experiment	2·935	4·083	.....	5·742	.....	6·920	7·920	8·785	2·1113
By series	2·952	4·099	4·967	5·692	6·326	6·897	7·904	8·785	
Body Io, by experiment	.....	4·081	.....	5·697	.....	6·934	7·958	8·784	2·1090
By series	2·948	4·095	4·963	5·689	6·324	6·894	7·902	8·784	

A continuation of Table 1.

Motive Powers requisite to overcome the Resistances of the several Bodies used in the Experiments of the Year 1797, when they are moving at Velocities, in Nautical Miles per Hour, as expressed underneath.

	Nautical miles per hour.							
	8	7	6	5	4	3	2	1
	Motive powers in pounds.							
Conductor and bar only	108.26	85.96	65.86	48.06	32.69	19.89	9.87	2.98
Conductor bar and body M	172.87	135.95	103.01	74.19	49.65	29.59	14.26	4.10
Body M alone	64.61	49.99	37.15	26.13	16.96	9.70	4.39	1.12
Conductor bar and body N	302.63	234.87	175.29	124.01	81.19	47.03	21.78	5.84
Body N alone	194.37	148.91	109.43	75.95	48.50	27.14	11.91	2.86
Conductor bar and body R	310.56	241.10	180.00	127.40	83.45	48.37	22.43	6.03
Body R alone	202.30	155.14	114.14	79.34	50.76	28.48	12.56	3.05
Conductor bar and body S	312.05	242.70	181.57	128.82	84.64	49.25	22.96	6.23
Body S alone	203.79	156.74	115.71	80.76	51.95	29.36	13.09	3.25
Conductor bar and body T	313.39	243.38	181.77	128.70	84.35	48.93	22.70	6.11
Body T alone	205.13	157.42	115.91	80.64	51.66	29.04	12.83	3.13
Conductor bar and body U	299.04	232.20	173.39	122.75	80.43	46.63	21.63	5.82
Body U alone	190.78	146.24	107.53	74.69	47.74	26.74	11.76	2.84
Conductor bar and body W	270.23	214.33	159.92	113.10	74.02	42.85	19.83	5.32
Body W alone	167.97	128.37	94.06	56.04	41.33	22.96	9.96	2.34
Conductor bar and body X	163.60	128.72	97.59	70.34	47.12	28.11	13.57	3.91
Body X alone	55.34	42.76	31.73	22.28	14.43	8.22	3.70	0.93
Conductor bar and body Y	154.55	121.67	92.31	66.59	44.65	26.67	12.90	3.73
Body Y alone	46.29	35.71	26.45	18.53	11.96	6.78	3.03	0.75
Conductor bar and body Z	173.13	135.62	102.31	73.30	48.74	28.80	13.72	3.86
Body Z alone	64.87	49.66	36.45	25.24	16.05	8.91	3.85	0.88

A continuation of Table 1.

Velocities of the several Bodies used in the Year 1797, *as obtained by Experiment, and also as brought into a regular Series by the Method specified in Chapter* 2.

	Motive powers in pounds avoirdupois.									Power of the Velocity
	6	12	24	36	48	60	72	96	120	
	Velocities, in feet, per second.									
Conductor and bar, by experiment ..	2·530	3·700	5·598	7·280	8·541	9·563	10·683	......	......	
By series	2·535	3·787	5·656	7·152	8·448	9·613	10·683	12·619	14·358	1·7276
Body M, by experiment	.....	3·056	.....	5·6 8	6·650	.....	8·315	......	......	
By series	2·091	3·073	4·516	5·657	6·638	7·514	8·315	9·756	11·044	1·7998
Body N, by experiment	.....	.....	3·578	.....	5·081	.....	6·280	7·388	8·279	
By series	1·742	2·470	3·559	4·407	5·128	5·768	6·349	7·388	8·310	1·8982
Body R, by experiment	.....	.....	3·511	4·306	5·012	.....	6·249	......	8·192	
By series	1·687	2·432	3·505	4·341	5·052	5·683	6·257	7·282	8·192	1·8958
Body S, by experiment	.....	2·412	3·445	.....	4·970	.....	6·224	7·237	8·142	
By series	1·658	2·396	3·463	4·295	5·004	5·634	6·207	7·232	8·142	1·8823
Body T, by experiment	.....	2·426	3·482	4·298	4·968	.....	6·213	7·315	8·148	
By series	1·675	2·415	3·483	4·314	5·022	5·650	6·221	7·242	8·148	1·8935
Body U, by experiment	.....	2·478	3·568	4·432	5·131	.....	6·380	7·441	8·374	
By series	1·719	2·478	3·573	4·425	5·151	5·795	6·380	7·426	8·355	1·8946
Body W, by experiment	.....	2·616	3·663	.....	5·395	.....	6·672	7·756	......	
By series	1·803	2·596	3·739	4·629	5·385	6·057	6·666	7·756	8·723	1·9000
Body X, by experiment	.....	3·189	4·636	5·763	6·834	.....	8·593	......	......	
By series	2·147	3·158	4·646	5·823	6·834	7·738	8·565	10·053	11·384	1·7958
Body Y, by experiment	.....	3·270	4·798	6·041	7·112	.....	......	10·370	......	
By series	2·206	3·248	4·783	5·997	7·042	7·977	8·831	10·370	11·746	1·7914
Body Z, by experiment	.....	3·130	4·515	.....	6·838	.....	8·471	9·799	......	
By series	2·152	3·143	4·592	5·731	6·709	7·578	8·373	9·799	11·071	1·8288

A continuation of Table 1.

Motive Powers requisite to overcome the Resistances of the several Bodies used in the Experiments of the Year 1796, *when they are moving at Velocities in Nautical Miles per Hour, as expressed underneath.*

	Nautical miles per hour.							
	8	7	6	5	4	3	2	1
	Motive powers in pounds.							
Conductor and bars only	108·45	84·04	62·61	44·30	28·87	16·67	7·68	2·05
Conductor bars and Apa	170·28	132·60	99·35	70·61	46·49	27·13	12·70	3·47
Body Apa alone	61·83	48·56	36·74	26·41	17·62	10·46	5·02	1·42
Conductor bars and Ape..............	184·44	143·57	107·52	76·39	50·27	29·31	13·70	3·74
Body Ape alone	75·99	59·53	44·91	32·19	21·40	12·64	6·02	1·69
Conductor bars and Apk	183·92	142·99	106·94	75·84	49·80	28·96	13·57	3·72
Body Apk alone	75·47	58·95	44·33	31·64	20·93	12·29	5·89	1·67
Conductor bars and Apl..............	181·18	141·16	105·82	75·36	49·59	28·96	13·57	3·72
Body Apl alone	72·73	57·12	43·21	31·06	20·72	12·29	5·89	1·67
Conductor bars and Api	194·79	151·37	113·13	80·17	52·59	30·54	14·20	3·83
Body Api alone......................	86·34	67·33	50·52	35·97	23·72	13·87	6·52	1·78
Conductor bars and Epa..............	181·50	141·33	105·86	75·22	49·51	28·88	13·51	3·68
Body Epa alone	73·05	57·29	43·25	31·02	20·64	12·21	5·83	1·63
Conductor bars and Kpa	181·59	141·22	105·64	74·94	49·23	28·64	13·35	3·62
Body Kpa alone	73·14	57·18	43·03	30·74	20·36	11·97	5·67	1·57
Conductor bars and Lpa..............	179·73	139·85	104·69	74·33	48·88	28·47	13·29	3·61
Body Lpa alone	71·28	55·81	42·08	30·13	20·01	11·80	5·61	1·56
Conductor bars and Ipa	284·10	219·45	162·88	114·48	74·36	42·63	19·46	5·09
Body Ipa alone......................	175·65	135·41	100·27	70·28	45·49	25·96	11·78	3·04
Conductor bars and Ipi	306·92	226·90	175·69	123·36	80·03	45·81	20·87	5·44
Body Ipi alone	198·47	152·86	113·08	79·16	51·16	29·14	13·19	3·39
Conductor bars and long friction [1] plank	169·23	131·81	98·78	70·22	46·25	27·00	12·64	3·45
Long friction plank alone	60·78	47·77	36·17	26·02	17·38	10·33	4·96	1·40
Conductr bars and short friction plank	144·19	111·80	83·35	58·90	38·50	22·26	10·28	2·75
Short friction plank alone	35·74	27·76	20·74	14·70	9·63	5·59	2·60	0·70

[1] The long friction plank contains exactly 50 square feet of surface for friction more than the short friction plank.

A continuation of Table 1.

***Velocities of the several Bodies used in the Year* 1796, *as obtained by Experiment, and also as brought into a regular Series by the Method specified in Chapter* 2.**

	Motive powers in pounds avoirdupois.										Power of the Velocity.
	6	12	24	36	48	60	72	96	120	144	
	Velocities, in feet, per second.										
Conductor and bars by experiment..	.....	4·245	.....	7·650	8·886	9·922	10·971	......	......	......	1·9095
By series........	2·971	4·271	6·140	7·593	8·828	9·922	10·916	12·691	14·264	15·693	
Body Apa, by experiment	2·281	3·316	4·729	5·820	6·818	7·753	8·543	......	......	......	1·8728*
By series........	2·267	3·282	4·752	5·900	6·880	7·751	8·543	9·961	11·222	12·369	
Body Ape, by experiment	2·163	3·126	4·560	.....	6·519*	.....	8·102	......	......	......	1·8752
By series........	2·177	3·151	4·560	5·661	6·599	7·433	8·192	9·550	10·757	11·856	
Body Apk, by experiment	2·197	3·178	4·565	.....	6·633	.....	......	......	......	......	1·8848
By series........	2·201	3·179	4·592	5·694	6·633	7·467	8·225	9·581	10·785	11·881	
Body Apl, by experiment	.....	3·167	4·582	.....	6·645	.....	8·257	......	......	......	1·8693
By series........	2·185	3·166	4·588	5·699	6·647	7·490	8·257	9·631	10·852	11·963	
Body Api, by experiment........	2·146	3·086	4·448	5·534	6·366*	7·132*	7·815*	......	......	......	1·8890
By series........	2·143	3·094	4·465	5·534	6·444	7·252	7·987	9·301	10·467	11·528	
Body Epa, by experiment........	2·220	3·175	4·554	5·613	6·620	7·494	......	9·594	10·789	11·920	1·8742
By series........	2·194	3·175	4·596	5·706	6·653	7·494	8·260	9·630	......	11·956	
Body Kpa, by experiment	2·212	3·207	4·607	.....	6·655	7·513	......	......	......	......	1·8830
By series........	2·212	3·196	4·618	5·728	6·673	7·513	8·277	9·643	10·856	11·960	
Body Lpa, by experiment........	.....	3·203	4·630	.....	6·699	......	8·276*	......	......	......	1·8786
By series........	2·215	3·203	4·632	5·748	6·699	7·544	8·313	9·688	10·910	12·022	
Body Ipa, by experiment........	1·828	2·631	3·745	4·599	5·344	6·069	6·652	7·683	8·593	9·453	1·9338
By series........	1·840	2·634	3·769	4·648	5·394	6·054	6·652	7·719	8·663	9·520	
Body Ipi, by experiment	.....	2·538	3·666	.....	5·167	......	6·423	7·429	......	......	1·9392
By series........	1·778	2·542	3·635	4·480	5·196	5·830	6·405	7·429	8·335	9·157	
Long friction plank, by experiment	.....	3·325	.....	5·916	6·900	7·773	......	10·053	......	......	1·8714
By series........	2·271	3·289	4·764	5·916	6·899	7·773	8·568	9·992	11·258	12·410	
Short friction plank, by experiment	2·544	.....	5·277	6·522	7·555	8·475	9·395	......	......	......	1·905
By series........	2·549	3·668	.....	6·530	7·594	8·548	9·395	10·927	12·284	13·518	

The velocities marked thus * are doubtful experiments, and are not, therefore, used in computing the regular series.

TABLE II.—*On Friction.*

Showing the Motive Powers requisite to overcome the Resistance arising from the Friction alone of the Water, which takes place against the several Surfaces of the different Bodies respectively: and also the Square Feet, and Decimal Parts of Square Feet, which are contained in the said Surfaces of said Bodies respectively.

Of the bodies used in the year 1798.				Nautical miles per hour. 1	2	3	4	5	6	7	8
				Motive powers in pounds.							
From the motive power requisite to overcome the resistances of the long friction plank, as found in table 1, page 385				1·435	5·482	11·807	20·159	30·329	42·146	55·432	70·048
Deduct the motive power requisite to overcome the resistance of the short friction plank, as found in table 1, page 385				0·872	3·490	7·739	13·517	20·731	29·307	39·145	50·192
Remains the motive power requisite to overcome the resistances arising from the friction, alone, of the water against 46 square feet of surface, and from whence the effect of the friction of the water against the several surfaces of the following bodies is computed according to the proportion which the said surfaces respectively bear to 46 square feet				0·563	1·992	4·068	6·642	9·598	12·839	16·287	19·856
The body Ao contains	In its top surface	4·71	Friction	0·058	0·20	0·42	0·68	0·98	1·31	1·67	2·03
	Sides and bottom surface	21·71		0·266	0·95	1·91	3·13	4·53	6·06	7·68	9·37
	Total surface	26·42		0·324	1·15	2·33	3·81	5·51	7·37	9·35	11·40
The body Aa contains	In its top surface	3·96	Friction	0·048	0·17	0·35	0·57	0·83	1·11	1·40	1·71
	Sides and bottom surface	17·96		0·220	0·78	1·57	2·59	3·75	5·01	6·36	7·75
	Total surface	21·92		0·268	0·95	1·92	3·16	4·58	6·11	7·76	9·46
The body Ab, or Ba, contains	In its top surface	4·26	Friction	0·052	0·18	0·38	0·62	0·89	1·19	1·51	1·84
	Sides and bottom surface	18·28		0·224	0·79	1·62	2·64	3·81	5·10	6·47	7·89
	Total surface	22·54		0·276	0·97	2·00	3·26	4·70	6·29	7·98	9·73

A continuation of Table 2, on Friction.

Of the bodies used in the year 1798.				Motive powers in pounds.							
The body Ac, or Ca, contains	In its top surface	4·80	Friction	0·059	0·21	0·42	0·69	1·00	1·34	1·70	2·07
	Sides and bottom surface..	18·85		0·231	0·82	1·67	2·72	3·93	5·26	6·67	8·14
	Total surface............	23·65		0·290	1·02	2·09	3·42	4·93	6·60	8·37	10·21
The body Ad, or Da, contains	In its top surface	3·45	Friction	0·042	0·15	0·31	0·50	0·72	0·96	1·22	1·49
	Sides and bottom surface..	15·45		0·189	0·67	1·37	2·23	3·22	4·31	5·47	6·67
	Total surface	18·90		0·231	0·82	1·67	2·73	3·94	5·28	6·69	8·16
The body Ae, or Ea, contains	In its top surface	3·19	Friction	0·039	0·14	0·28	0·46	0·67	0·89	1·13	1·38
	Sides and bottom surface..	14·19		0·174	0·61	1·26	2·05	2·96	3·96	5·02	6·13
	Total surface............	17·38		0·233	0·75	1·54	2·51	3·63	4·85	6·15	7·50
The body Af, or Fa, contains..	In its top surface	2·91	Friction	0·036	0·13	0·26	0·42	0·61	0·81	1·03	1·26
	Sides and bottom surface..	12·91		0·158	0·56	1·14	1·86	2·69	3·60	4·57	5·57
	Total surface	15·82		0·194	0·69	1·40	2·28	3·30	4·42	5·60	6·83
The body Ag, or Ga, contains	In its top surface	3·09	Friction	0·038	0·13	0·27	0·45	0·64	0·86	1·09	1·33
	Sides and bottom surface..	13·19		0·161	0·57	1·17	1·90	2·75	3·68	4·67	5·69
	Total surface............	16·28		0·199	0·70	1·44	2·35	3·40	4·54	5·76	7·03
The body Ah, or Ha, contains	In its top surface	2·87	Friction	0·035	0·12	0·25	0·41	0·60	0·80	1·02	1·24
	Sides and bottom surface..	12·44		0·152	0·54	1·10	1·80	2·60	3·47	4·40	5·37
	Total surface............	15·31		0·187	0·26	1·35	2·21	3·19	4·27	5·42	6·61
The body Ai, or Ia, contains ..	In its top surface	2·48	Friction	0·030	0·11	0·22	0·36	0·52	0·69	0·88	1·07
	Sides and bottom surface..	10·48		0·128	0·45	0·93	1·51	2·19	2·93	3·71	4·52
	Total surface	12·96		0·158	0·56	1·14	1·87	2·70	3·62	4·59	5·59
The body Ho contains........	In its top surface	3·62	Friction	0·045	0·16	0·32	0·52	0·76	1·01	1·28	1·56
	Sides and bottom surface..	16·19		0·198	0·70	1·42	2·34	3·38	4·52	5·73	6·99
	Total surface	19·81		0·243	0·86	1·74	2·86	4·14	5·53	7·01	8·56
The body Io contains	In its top surface	3·23	Friction	0·040	0·14	0·29	0·47	0·67	0·90	1·14	1·39
	Sides and bottom surface..	14·23		0·174	0·61	1·25	2·05	2·97	3·97	5·03	6·14
	Total surface	17·46		0·214	0·75	1·54	2·52	3·64	4·88	6·17	7·53

The friction, as found by these experiments, is applicable to surfaces that are planed smooth and painted (and not water soaken) such as the bodies used in the years 1798 and 1797.

A continuation of Table 2, on Friction.

		Nautical miles per hour.							
		1	2	3	4	5	6	7	8
Of the bodies used in the year 1797.		Motive powers in pounds.							
The total surface which is contained in the two sides, and top and bottom, of the bodies M or N, is	8·96 Friction	0·110	0·39	0·79	1·39	1·87	2·50	3·17	3·87
The total surface which is contained in the two sides, and top and bottom, of the body R, is	4·00 Friction	0·049	0·17	0·35	0·58	0·83	1·12	1·42	1·75
The total circular surface which is contained in the bodies U or Z is, each	4·00 Friction	0·049	0·17	0·35	0·58	0·83	1·12	1·42	1·73
The total circular surface which is contained in the bodies W or X is, each	6·00 Friction	0·073	0·26	0·53	0·87	1·25	1·67	2·12	2·59
The total circular surface which is contained in the body Y is	..8·00 Friction	0·098	0·34	0·71	1·16	1·67	2·23	2·83	3·48
Of the bodies used in the year 1796.									
From the motive power requisite to overcome the resistance of the long friction plank, as found in table 1, page 390.....................................		1·40	4·96	10·33	17·38	26·02	36·17	47·77	60·78
Deduct the motive power requisite to overcome the resistance of the short friction plank, as found in table 1, page 390		0·70	2·60	5·59	9·63	14·70	20·74	27·76	35·74
Remains the motive power requisite to overcome the resistance arising from the friction, alone, of the water against 50 square feet of surface, and from whence the effect of the friction against the several surfaces of the following bodies is computed, according to the proportion which the said surfaces respectively bear to 50 square feet		0·70	2·36	4·74	7·75	11·32	15·43	20·01	25·04

A continuation of Table 2, on Friction.

Of the bodies used in the year 1796.				Motive powers in pounds.							
The body APa contains	In its top surface	12·96	Friction	0·18	0·61	1·23	2·01	2·93	4·00	5·19	6·49
	Sides and bottom surface..	44·96		0·63	2·12	4·26	6·97	10·18	13·84	17·99	22·52
	Total surface	57·92		0.81	2·73	5·49	8·98	13·11	17·84	23·18	29·01
The body APe, or EPa, contains	In its top surface	12·19	Friction	0·17	0·58	1·16	1·89	2·76	3·76	4·88	6·10
	Sides and bottom surface..	41·19		0·58	1·94	3·90	6·38	9·33	12·71	16·48	20·63
	Total surface	53·38		0·75	2·53	5·06	8·27	12·09	16·47	21·36	26·73
The body APk, or KPa, contains	In its top surface	14·31	Friction	0·20	0·68	1·36	2·22	3·24	4·42	5·73	7·17
	Sides and bottom surface..	43·31		0·61	2·04	4·11	6·71	9·81	13·37	17·33	21·70
	Total surface	57·62		0·81	2·72	5·46	8·93	13·05	17·79	23·06	28·87
The body APl, or LPa, contains	In its top surface	14·74	Friction	0·21	0·70	1·40	2·28	3·34	4·55	5·90	7·38
	Sides and bottom surface..	44·21		0·62	2·09	4·19	6·85	10·01	13·64	17·69	22·14
	Total surface	58·95		0·83	2·78	5·59	9·14	13·35	18·19	23·59	29·52
The body APi, or IPa, contains	In its top surface	11·48	Friction	0·16	0·54	1·09	1·78	2·60	3·54	4·59	5·75
	Sides and bottom surface..	37·48		0·53	1·77	3·55	5·81	8·49	11·57	15·00	18·77
	Total surface	48·96		0·69	2·31	4·64	7·59	11·08	15·11	19·59	24·52
The body IPi contains........	In its top surface	10·00	Friction	0·14	0·47	0·95	1·55	2·26	3·09	4·00	5·01
	Sides and bottom surface..	30·00		0·42	1·42	2·84	4·65	6·79	9·26	12·01	15·02
	Total surface	40·00		0·56	1·89	3·79	6·20	9·06	12·34	16·01	20·03

The friction, as found by these experiments, is applicable to such surfaces as have been planed smooth, and painted, and immersed a considerable time in the water, so as to be pretty much water soaken, (but clean from slime or dirt,) such as the bodies used in the year 1796.

TABLE III.

Analysis of the total Resistance of the different Bodies used in the Year 1798; respectively showing, at one view, the Motive Power which is requisite to overcome the various Resistances of the different Bodies, as applicable to Practice, and as specified below.

Of the bodies used in the year 1798.			Nautical miles per hour.							
			1	2	3	4	5	6	7	8
			Motive powers in pounds.							
From	Total resistance of [1] Ao, per table 1	=	0·73	2·64	6·52	11·38	17·43	24·62	32·85	42·07
Deduct	Friction on top surface, table 2	=	0·06	0·20	0·42	0·68	0·98	1·31	1·67	2·03
Remains	Resistance as a ship	=	0·67	2·74	6·10	19·70	16·45	23·31	31·18	40·04
Then deduct	Friction on sides and bottom, table 2 ..	=	0·27	0·95	1·91	3·13	4·53	6·06	7·68	9·37
Remains	Plus and minus pressure..............	=	0·40	1·79	4·19	7·57	11·92	17·25	23·50	30·67
Then deduct	Minus pressure (see chap. 5)	=	0·00	0·00	0·00	0·00	0·00	0·00	0·00	0·00
Remains	Plus pressure of head end A	=	0·40	1·79	4·19	7·57	11·92	17·25	23·50	30·67
From the	Total resistance of Ba, table 1	=	0·63	2·59	5·86	10·38	16·12	23·04	31·08	40·22
Deduct	Friction on top surface, table 2........	=	0·05	0·18	0·38	0·62	0·89	1·19	1·51	1·84
Remains	Resistance as a ship..................	=	0·58	2·41	5·48	9·76	15·23	21·85	29·57	38·38
Then deduct	Friction on sides and bottom, table 2 ..	=	0·22	0·79	1·62	2·64	3·81	5·10	6·47	7·89
Remains	Plus and minus pressure..............	=	0·36	1·62	3·86	7·12	11·42	16·75	23·10	30·49
Then deduct	Minus pressure of a, as opposite	=	0·04	0·13	0·27	0·44	0·64	0·89	1·16	1·46
Remains	Plus pressure of head end B	=	0·32	1·49	3·59	6·68	10·78	15·86	21·94	20·03

[1] The bodies move in the direction of the first-mentioned letter.

Table 3, continued.

Of the bodies used in the year 1798.		Motive powers in pounds.							
From the	Total resistance of Ca, table 1 .... =	0·76	3·05	6·77	11·82	18·12	25·60	34·17	43·79
Deduct	Friction on top surface, table 2 .... =	0·06	0·21	0·42	0·69	1·00	1·34	1·70	2·07
Remains	Resistance as a ship .... =	0·70	2·84	6·35	11·13	17·12	24·26	32·47	41·72
Then deduct	Friction on sides and bottom, table 2 .. =	0·23	0·82	1·67	2·72	3·93	5·26	6·67	8·14
Remains	Plus and minus pressure.............. =	0·47	2·02	4·68	8·41	13·19	19·00	25·80	33·58
Then deduct	Minus pressure of a, as opposite ...... =	0·04	0·13	0·27	0·44	0·64	0·89	1·16	1·46
Remains	Plus pressure of head end C .... =	0·43	1·89	4·41	7·97	12·55	18·11	24·64	32·12
From the	Total resistance of Da, table 1 .... =	0·75	3·03	6·76	11·89	18·33	26·04	34·93	44·96
Deduct	Friction on top surface, table 2 ...... =	0·04	0·15	0·31	0·50	0·72	0·96	1·22	1·49
Remains	Resistance as a ship .... =	0·71	2·88	6·45	11·39	17·61	25·08	33·71	43·47
Then deduct	Friction on sides and bottom, table 2 .. =	0·19	0·67	1·37	2·23	3·22	4·31	5·47	6·67
Remains	Plus and minus pressure.............. =	0·52	2·21	5·08	9·16	14·39	20·77	28·24	36·80
Then deduct	Minus pressure of a, as opposite ...... =	0·04	0·13	0·27	0·44	0·64	0·89	1·16	1·46
Remains	Plus pressure of head end D .... =	0·48	2·08	4·81	8·72	13·75	19·88	27·08	35·34
From the	Total resistance of Ea, table 1 .... =	0·83	3·38	7·57	13·33	10·58	29·27	39·32	50·68
Deduct	Friction on top surface, table 2........ =	0·04	0·14	0·28	0·46	0·67	0·89	1·13	1·38
Remains	Resistance as a ship.................. =	0·79	3·24	7·29	12·87	19·91	28·38	38·19	49·30
Then deduct	Friction on sides and bottom, table 2 .. =	0·17	0·61	1·26	2·05	2·96	3·96	5·02	6·13
Remains	Plus and minus pressure .... =	0·62	2·63	6·03	10·82	16·95	24·42	33·17	43·17
Then deduct	Minus pressure of a, as opposite ...... =	0·04	0·13	0·27	0·44	0·64	0·89	1·16	1·46
Remains	Plus pressure of head end E .... =	0·58	2·50	5·76	10·38	16·31	23·53	32·01	41·71

Table 3, continued.

Of the bodies used in the year 1798.			Motive powers in pounds.							
From	Total resistance of Aa, per table 1	=	0·71	2·87	6·38	11·17	17·14	24·26	32·42	41·59
Deduct	Friction on top surface, table 2	=	0·05	0·17	0·35	0·57	0·83	1·11	1·40	1·71
Remains	Resistance as a ship	=	0·66	2·70	6·03	10·60	16·31	23·15	31·02	39·88
Then deduct	Friction on sides and bottom, table 2	=	0·22	0·78	1·57	2·59	3·75	5·01	6·36	7·75
Remains	Plus and minus pressure	=	0·44	1·92	4·46	8·01	12·56	18·14	24·66	32·13
Then deduct	Plus pressure of A, as opposite	=	0·40	1·79	4·19	7·57	11·92	17·25	23·50	30·67
Remains	Minus pressure of stern end a	=	0·04	0·13	0·27	0·44	0·64	0·89	1·16	1·46
From	Total resistance of Ab, table 1	=	0·67	2·76	6·23	11·02	17·09	24·40	32·89	42·53
Deduct	Friction on top surface, table 2	=	0·05	0·18	0·38	0·62	0·89	1·19	1·51	1·84
Remains	Resistance as a ship	=	0·62	2·58	5·85	10·40	16·20	23·21	31·38	40·69
Then deduct	Friction on sides and bottom, table 2	=	0·22	0·79	1·62	2·64	3·81	5·10	6·47	7·89
Remains	Plus and minus pressure	=	0·40	1·79	4·23	7·76	12·39	18·11	24·91	32·80
Then deduct	Plus pressure of A, as opposite	=	0·40	1·79	4·19	7·57	11·92	17·25	23·50	30·67
Remains	Minus pressure of stern end b	=	0·00	0·00	0·04	0·19	0·47	0·86	1·41	2·13
From	Total resistance of Ac, table 1	=	0·83	3·32	7·33	12·76	19·51	27·50	36·64	46·86
Deduct	Friction on top surface, table 2	=	0·06	0·21	0·42	0·69	1·00	1·34	1·70	2·07
Remains	Resistance as a ship	=	0·77	3·11	6·91	12·07	18·51	26·16	34·94	44·79
Then deduct	Friction on sides and bottom, table 2	=	0·23	0·84	1·67	2·72	3·93	5·26	6·67	8·14
Remains	Plus and minus pressure	=	0·54	2·29	5·24	9·35	14·58	20·90	28·27	36·65
Then deduct	Plus pressure of A, as opposite	=	0·40	1·79	4·19	7·57	11·92	17·25	23·50	30·67
Remains	Minus pressure of stern end c	=	0·14	0·50	1·05	1·78	2·66	3·65	4·77	5·98

Table 3, continued.

Of the bodies used in the year 1798.			Motive powers in pounds.							
From	Total resistance of Ad, table 1	=	0·82	3·25	7·16	12·42	18·93	26·62	35·36	45·11
Deduct	Friction on top surface, table 2	=	0·04	0·15	0·31	0·50	0·72	0·96	1·22	1·49
Remains	Resistance as a ship	=	0·78	3·10	6·85	11·92	18·21	25·66	34·14	43·62
Then deduct	Friction on sides and bottom, table 2	=	0·19	0·67	1·37	2·23	3·22	4·31	5·47	6·67
Remains	Plus and minus pressure	=	0·59	2·43	5·48	9·69	14·99	21·35	28·67	36·95
Then deduct	Plus pressure of A, as opposite	=	0·40	1·79	4·19	7·57	11·92	17·25	23·50	30·67
Remains	Minus pressure of stern end d	=	0·19	0·64	1·29	2·12	3·07	4·10	5·17	6·28
From	Total resistance of Ae, table 1	=	0·84	3·44	7·72	13·64	21·12	30·11	40·54	52·37
Deduct	Friction on top surface, table 2	=	0·04	0·14	0·28	0·46	0·67	0·89	1·13	1·38
Remains	Resistance as a ship	=	0·80	3·30	7·44	13·18	20·45	29·22	39·41	50·99
Then deduct	Friction on sides and bottom, table 2	=	0·17	0·61	1·26	2·05	2·96	3·96	5·02	6·13
Remains	Plus and minus pressure	=	0·63	2·69	6·18	11·13	17·49	25·26	34·39	44·86
Then deduct	Plus pressure of A, as opposite	=	0·40	1·79	4·19	7·57	11·92	17·25	23·50	30·67
Remains	Minus pressure of stern end e	=	0·23	0·90	1·99	3·56	5·57	8·01	10·89	14·19
From	Total resistance of Fa, table 1	=	0·97	3·93	8·83	15·57	24·10	4·36	46·25	59·73
Deduct	Friction on top surface, table 2	=	0·04	0·13	0·26	0·42	0·61	30·81	1·03	1·26
Remains	Resistance as a ship	=	0·93	3·80	8·57	15·15	23·49	3·55	45·22	58·47
Then deduct	Friction on sides and bottom, table 2	=	0·16	0·56	1·14	1·86	2·69	33·60	4·57	5·57
Remains	Plus and minus pressure	=	0·77	3·24	7·43	13·29	20·80	9·95	40·65	52·90
Then deduct	Minus pressure of a, before found	=	0·04	0·13	0·27	0·44	0·64	20·89	1·16	1·46
Remains	Plus pressure of head end F	=	0·73	3·11	7·16	12·85	20·16	29·06	39·49	51·44

Table 3, continued.

Of the bodies used in the year 1798.			Motive powers in pounds.							
From	Total resistance of Ga, table 1	=	0·66	2·71	6·12	10·86	16·87	24·12	32·57	42·17
Deduct	Friction on top surface, table 2	=	0·04	0·13	0·27	0·45	0·64	0·86	1·09	1·33
Remains	Resistance as a ship	=	0·62	2·58	5·85	10·41	16·23	23·26	31·48	41·84
Then deduct	Friction on sides and bottom, table 2	=	0·16	0·57	1·17	1·90	2·75	3·68	4·67	5·99
Remains	Plus and minus pressure	=	0·46	2·01	4·68	8·51	13·48	19·58	26·81	35·15
Then deduct	Minus pressure of a, before found	=	0·04	0·13	0·27	0·44	0·64	0·89	1·16	1·46
Remains	Plus pressure of head end G.	=	0·42	1·88	4·41	8·07	12·84	18·69	25·65	33·69
From	Total resistance of Ha, table 1	=	0·76	3·13	7·06	12·49	19·37	27·67	31·31	48·26
Deduct	Friction on top surface, table 2	=	0·04	0·12	0·25	0·41	0·60	0·80	1·02	1·24
Remains	Resistance as a ship	=	0·72	3·01	6·81	12·08	18·77	26·87	36·29	47·02
Then deduct	Friction on sides and bottom, table 2	=	0·15	0·54	1·10	1·80	2·60	3·47	4·40	5·37
Remains	Plus and minus pressure	=	0·57	2·47	5·71	10·28	16·17	23·40	31·89	41·65
Then deduct	Minus pressure of a, before found	=	0·04	0·13	0·27	0·44	0·64	0·89	1·16	1·46
Remains	Plus pressure of head end H	=	0·53	2·34	5·44	9·84	15·53	22·51	30·73	40·19
From	Total resistance of Ho, table 1	=	0·78	3·20	7·21	12·76	19·78	28·25	38·10	49·28
Deduct	Friction on top surface, table 2	=	0·05	0·16	0·32	0·52	0·76	1·01	1·28	1·56
Remains	Resistance as a ship	=	0·73	2·04	6·89	12·24	19·02	27·24	36·82	47·72
Then deduct	Friction on sides and bottom, table 2	=	0·20	0·70	1·42	2·34	3·38	4·52	5·73	6·99
Remains	Plus and minus pressure	=	0·53	2·34	5·47	9·90	15·64	22·72	31·09	40·73
Then deduct	Minus pressure of o, chap. 5	=	0·00	0·00	0·00	0·00	0·00	0·00	0·00	0·00
Remains	Plus pressure of head end H.	=	0·53	2·34	5·47	9·90	15·64	22·72	31·09	40·73

Table 3 continued.

Of the bodies used in the year 1798.			Motive powers in pounds.							
From	Total resistance of Ia, table 1	=	2·47	10·00	22·50	39·86	61·99	88·78	120·13	155·97
Deduct	Friction on top surface, table 2	=	0·03	0·11	0·22	0·36	0·52	0·69	0·88	1·07
Remains	Resistance as a ship	=	2·44	9·89	22·28	39·50	61·47	88·09	119·25	154·90
Then deduct	Friction on sides and bottom, table 2	=	0·13	0·45	0·93	1·51	2·19	2·93	3·71	4·52
Remains	Plus and minus pressure	=	2·31	9·44	21·35	37·99	59·28	85·16	115·54	150·38
Then deduct	Minus pressure of a, before found	=	0·04	0·13	0·27	0·44	0·64	0·89	1·16	1·46
Remains	Plus pressure of head end I	=	2·27	9·31	21·08	37·55	58·64	84·27	114·38	148·92
From	Total resistance of Af, table 1	=	1·13	4·69	10·69	19·13	29·95	43·14	58·65	76·44
Deduct	Friction on top surface, table 2	=	0·04	0·13	0·26	0·42	0·61	0·81	1·03	1·26
Remains	Resistance as a ship	=	1·09	4·56	10·43	18·71	29·34	42·33	57·62	75·18
Then deduct	Friction on sides and bottom, table 2	=	0·16	0·56	1·14	1·86	2·69	3·60	4·57	5·57
Remains	Plus and minus pressure	=	0·93	4·00	9·29	16·85	26·65	38·73	53·05	69·61
Then deduct	Plus pressure of A, before found	=	0·40	1·79	4·19	7·57	11·92	17·25	23·50	30·67
Remains	Minus pressure of stern end f	=	0·53	2·21	5·10	9·28	14·73	21·48	29·55	38·94
From	Total resistance of Ag, table 1	=	1·14	4·45	9·71	16·73	25·38	35·52	47·02	59·77
Deduct	Friction on top surface, table 2	=	0·04	0·13	0·27	0·45	0·64	0·86	1·09	1·33
Remains	Resistance as a ship	=	1·10	4·32	9·44	16·28	24·74	34·66	45·93	58·44
Then deduct	Friction on sides and bottom, table 2	=	0·16	0·57	1·17	1·90	2·75	3·68	4·67	5·69
Remains	Plus and minus pressure	=	0·94	3·75	8·27	14·38	21·99	30·98	41·26	52·75
Then deduct	Plus pressure of A, before found	=	0·40	1·79	4·19	7·57	11·92	17·25	23·50	30·67
Remains	Minus pressure of stern end g	=	0·54	1·96	4·08	6·81	10·07	13·73	17·76	22·08

Table 3 continued.

Of the bodies used in the year 1798.			Motive powers in pounds.							
From	Total resistance of Ah, table 1	=	0·90	3·65	8·15	14·32	22·08	31·37	42·09	54·20
Deduct	Friction on top surface, table 2	=	0·04	0·12	0·25	0·41	0·60	0·80	1·02	1·24
Remains	Resistance as a ship	=	0·86	3·53	7·90	13·91	21·48	30·57	41·07	52·96
Then deduct	Friction on sides and bottom, table 2	=	0·15	0·54	1·10	1·80	2·60	3·47	4·40	5·37
Remains	Plus and minus pressure	=	0·71	2·99	6·80	12·11	18·88	27·10	36·67	47·59
Then deduct	Plus pressure of A, before found	=	0·40	1·79	4·19	7·57	11·92	17·25	23·50	30·67
Remains	Minus pressure of stern end h	=	0·31	1·20	2·16	4·54	6·96	9·85	13·17	16·92
From	Total resistance of Ai, table 1	=	1·05	4·28	9·60	16·95	26·25	37·44	50·44	65·18
Deduct	Friction on top surface, table 2	=	0·03	0·11	0·22	0·36	0·52	0·69	0·88	1·07
Remains	Resistance as a ship	=	1·02	4·17	9·38	16·59	25·73	36·75	49·56	64·11
Then deduct	Friction on sides and bottom, table 2	=	0·13	0·45	0·93	1·51	2·19	2·93	3·71	4·52
Remains	Plus and minus pressure	=	0·89	3·72	8·45	15·08	23·54	33·82	45·85	59·59
Then deduct	Plus pressure of A, before found	=	0·40	1·79	4·19	7·57	11·92	17·25	23·50	30·67
Remains	Minus pressure of stern end i	=	0·49	1·93	4·26	7·51	11·62	16·57	22·35	28·92
From	Total resistance of Io, table 1,	=	2·49	10·04	22·56	39·93	62·02	88·78	120·06	155·78
Deduct	Friction on top surface, table 2	=	0·04	0·14	0·29	0·47	0·67	0·90	1·14	1·39
Remains	Resistance as a ship	=	2·45	9·90	22·27	39·46	61·35	87·88	118·92	154·39
Then deduct	Friction on sides and bottom, table 2	=	0·17	0·61	1·25	2·05	2·97	3·97	5·03	6·14
Remains	Plus and minus pressure	=	2·28	9·29	21·02	37·41	58·38	83·91	113·89	148·25
Then deduct	Minus pressure of O, chap. 5	=	0·00	0·00	0·00	0·00	0·00	0·00	0·00	0·00
Remains	Plus pressure of head end I	=	2·28	9·29	21·02	37·41	58·38	83·91	113·89	148·25

Table 3 continued.

Analysis of the total Resistance of the different Bodies used in the Year 1796, respectively; showing, at one view, the Motive Powers which are requisite to overcome the various Resistances of the different Bodies, as applicable to Practice, and as specified below.

Of the bodies used in the year 1796.			Nautical miles per hour. 1	2	3	4	5	6	7	8
			Motive powers in pounds.							
From	Total resistance of APa, table 1	=	1·42	5·02	10·46	17·62	26·41	36·74	48·56	61·83
Deduct	Friction on top surface, table 2	=	0·18	0·61	1·23	2·01	2·93	4·00	5·19	6·49
Remains	Resistance as a ship	=	1·24	4·41	9·23	15·61	23·48	32·74	43·37	55·34
Then deduct	Friction on sides and bottom, table 2	=	0·63	2·24	4·26	6·97	10·18	13·84	17·99	22·52
Remains	Plus and minus pressure	=	0·61	2·29	4·97	8·64	13·30	18·90	25·38	32·82
Then deduct	Minus pressure of a, as opposite	=	0·21	0·50	0·78	1·07	1·38	1·65	1·88	2·15
Remains	Plus pressure of head end A	=	0·40	1·79	4·19	7·57	11·92	17·25	23·50	30·67
From	Total resistance of EPa, table 1	=	1·63	5·83	12·21	20·64	31·02	43·25	57·29	73·05
Deduct	Friction on top surface, table 2	=	0·17	0·58	1·16	1·89	2·76	3·76	4·88	6·10
Remains	Resistance as a ship	=	1·46	5·25	11·05	18·75	28·26	39·49	52·41	66·95
Then deduct	Friction on sides and bottom, table 2	=	0·58	1·94	3·90	6·38	9·33	12·71	16·48	20·63
Remains	Plus and minus pressure	=	0·88	3·31	7·15	12·37	18·93	26·78	35·93	46·32
Then deduct	Minus pressure of a, as opposite	=	0·21	0·50	0·78	1·07	1·38	1·65	1·88	2·15
Remains	Plus pressure of head end E	=	0·67	2·81	6·37	11·30	17·55	25·13	34·05	44·17

Table 3 continued.

Of the bodies used in the year 1796.			Motive powers in pounds.							
From	Total resistance of Kpa, table 1	=	1·57	5·67	11·97	20·36	30·74	43·03	57·18	73·14
Deduct	Friction on top surface, table 2	=	0·20	0·68	1·36	2·22	3·24	4·42	5·73	7·17
Remains	Resistance as a ship	=	1·37	4·99	10·61	18·14	27·50	38·61	51·45	65·97
Then deduct	Friction on sides and bottom, table 2....	=	0·61	2·04	4·11	6·71	9·81	13·37	17·33	21·70
Remains	Plus and minus pressure	=	0·76	2·95	6·50	11·43	17·69	25·24	34·12	44·27
Then deduct	Minus pressure of a, as opposite........	=	0·21	0·50	0·78	1·07	1·38	1·65	1·88	2·15
Remains	Plus pressure of head end K	=	0·55	2·45	5·72	10·36	16·31	23·59	32·24	44·12
From	Total resistance of Lpa, table 1	=	1·56	5·61	11·80	20·01	30·13	42·08	55·81	71·28
Deduct	Friction on top surface, table 2	=	0·21	0·70	1·40	2·28	3·34	4·55	5·90	7·38
Remains	Resistance as a ship	=	1·35	4·91	10·40	17·73	26·79	37·53	49·91	63·90
Then deduct	Friction on sides and bottom, table 2....	=	0·62	2·09	4·19	6·85	10·01	13·64	17·69	22·14
Remains	Plus and minus pressure	=	0·73	2·82	6·21	10·88	16·78	23·89	32·22	41·76
Then deduct	Minus pressure of a, as opposite........	=	0·21	0·50	0·78	1·07	1·38	1·65	1·88	2·15
Remains	Plus pressure of head end L.	=	0·52	2·32	5·43	9·81	15·40	22·24	30·34	39·61
From	Total resistance of IPa, table 1	=	3·04	11·78	25·56	45·49	70·28	100·27	135·41	175·65
Deduct	Friction on top surface, table 2	=	0·16	0·54	1·09	1·78	2·60	3·54	4·59	5·75
Remains	Resistance as a ship	=	2·88	11·24	24·87	43·71	67·68	96·73	130·82	169·90
Then deduct	Friction on sides and bottom, table 2....	=	0·53	1·77	3·55	5·81	8·49	11·57	15·00	18·77
Remains	Plus and minus pressure	=	2·35	9·47	21·32	37·90	59·19	85·16	115·82	151·13
Then deduct	Minus pressure of a, as opposite	=	0·21	0·50	0·78	1·07	1·38	1·65	1·88	2·15
Remains	Plus pressure of head end I	=	2·14	8·97	20·54	36·83	57·81	83·51	113·94	148·98
From	Total resistance of APa, table 1	=	1·42	5·02	10·46	17·62	26·41	36·74	48·56	61·83
Deduct	Friction on top surface, table 2	=	0·18	0·61	1·23	2·01	2·93	4·00	5·19	6·49
Remains	Resistance as a ship	=	1·24	4·41	9·23	15·61	23·48	32·74	43·37	55·34
Then deduct	Friction on sides and bottom, table 2....	=	0·63	2·12	4·26	6·97	10·18	13·84	17·99	22·52
Remains	Plus and minus pressure	=	0·61	2·29	4·97	8·64	13·30	18·90	25·38	32·82
Then deduct	Plus pressure of A, experiment 1798	=	0·40	1·79	4·19	7·57	11·92	17·25	23·50	30·67
Remains	Minus pressure of stern end a..........	=	0·21	0·50	0·78	1·07	1·38	1·65	1·88	2·15

Table 3 continued.

Of the bodies used in the year 1796.			Motive powers in pounds.							
From	Total resistance of APe, table 1	=	1·69	6·02	12·64	21·40	32·19	44·91	59·53	75·99
Deduct	Friction on top surface, table 2	=	0·17	0·58	1·16	1·89	2·76	3·76	4·88	6·10
Remains	Resistance as a ship	=	1·52	5·44	11·48	19·51	29·43	41·15	54·65	69·89
Then deduct	Friction on sides and bottom, table 2	=	0·58	1·94	3·90	6·38	9·33	12·71	16·48	20·63
Remains	Plus and minus pressure	=	0·94	3·50	7·58	13·13	20·10	28·44	38·17	49·26
Then deduct	Plus pressure of A, experiment 1798	=	0·40	1·79	4·19	7·57	11·92	17·25	23·50	30·67
Remains	Minus pressure of stern end e..........	=	0·54	1·71	3·39	5·56	8·18	11·19	14·67	18·59
From	Total resistance of APk, table 1........	=	1·60	5·81	12·29	20·93	31·64	44·33	58·95	75·47
Deduct	Friction on top surface, table 2	=	0·20	0·68	1·36	2·22	3·24	4·42	5·73	7·17
Remains	Resistance as a ship	=	1·40	5·13	10·93	18·71	28·40	39·91	53·22	68·30
Then deduct	Friction on sides and bottom, table 2....	=	0·61	2·04	4·11	6·71	9·81	13·37	17·33	21·70
Remains	Plus and minus pressure	=	0·79	3·09	6·82	12·00	18·59	26·54	35·89	46·60
Then deduct	Plus pressure of A, experiment 1798....	=	0·40	1·79	4·19	7·57	11·92	17·25	23·50	30·67
Remains	Minus pressure of stern end k..........	=	0·39	1·30	2·63	4·43	6·67	9·29	12·39	15·93
From	Total resistance of APl, table 1	=	1·67	5·89	12·29	20·72	31·06	43·21	57·12	72·73
Deduct	Friction on top surface, table 2	=	0·21	0·70	1·40	2·28	3·34	4·55	5·90	7·38
Remains	Resistance as a ship..................	=	1·46	5·19	10·89	18·44	27·72	38·66	51·22	65·35
Then deduct	Friction on sides and bottom, table 2....	=	0·62	2·09	4·19	6·85	10·01	13·64	17·69	22·14
Remains	Plus and minus pressure	=	0·84	3·10	6·70	11·59	17·71	25·02	33·53	43·21
Then deduct	Plus pressure of A, experiment 1798....	=	0·40	1·79	4·19	7·57	11·92	17·25	23·50	30·67
Remains	Minus pressure of stern end l..........	=	0·44	1·31	2·51	4·02	5·79	7·77	10·03	12·54
From	Total resistance of AP1, table 1	=	1·78	6·52	13·87	23·72	35·97	50·52	67·33	86·34
Deduct	Friction on top surface, table 2	=	0·16	0·54	1·09	1·78	2·60	3·54	4·59	5·75
Remains	Resistance as a ship	=	1·62	5·98	12·78	21·94	33·37	46·98	62·74	80·59
Then deduct	Friction on sides and bottom, table 2....	=	0·53	1·77	3·55	5·81	8·49	11·57	15·00	18·77
Remains	Plus and minus pressure	=	1·09	4·21	9·23	16·13	24·88	35·41	47·74	61·82
Then deduct	Plus pressure of A, experiment 1798....	=	0·40	1·79	4·19	7·57	11·92	17·25	23·50	30·67
Remains	Minus pressure of stern 1..............	=	0·69	2·42	5·04	8·56	12·96	18·16	24·24	31·15

Art. XXVI.—*Proportions of the Masts and Yards of Lateen rigged Vessels and Polacres.*

(*To the Editors of Papers on Naval Architecture.*)

Gentlemen,

Considering that the proportions of the masts and yards of the vessels peculiar to the Mediterranean, may not be generally known in this country, I beg to offer, for insertion in your work, the following methods, which have been much used for masting lateen rigged vessels and polacres, which I hope may be interesting to some of your readers.

I remain, gentlemen, your very obedient servant,

A. Z.

For lateen rigged vessels:

Main-mast,	in length,	$2\frac{4}{5}$	the main breadth.
	in diameter,	1	inch per yard.
Fore-mast,	in length,	$2\frac{1}{4}$	the main breadth.
	in diameter,	1	inch per yard.
Mizen-mast,	in length,	$1\frac{1}{2}$	the main breadth.
	in diameter,	1	inch per yard.
Main-yard,	in length,	$4\frac{4}{5}$	the main breadth.
Fore-yard,	in length,	4	times the breadth.
Mizen yard,	ditto,	$2\frac{1}{3}$	the breadth.

When carrying square yards, in addition to the lateen yards, as xebecks.

Main-yard,	$2\frac{1}{2}$	the main breadth.
Fore-yard,	2	the main breadth.
Topsail-yards	$\frac{2}{3}$	the lengths of their respective yards.

For polacres of two masts.

Fore-mast.—Length to the hounds, twice the main breadth; of the top-mast, $\frac{5}{8}$ of the part from the heel to the hounds; and of the top-gallant-mast, half the length of the top-mast; making the whole length $3\frac{7}{8}$ of the main breadth. The top-gallant-mast is now generally made to fit with cross-trees, in the larger polacres, after the usual mode of masting, in consequence of the great length it would require in one stick.

Main-mast.—Length to the hounds $\frac{1}{10}$ more than that of the fore-mast; top-mast, $\frac{5}{8}$ of the part from the heel to the hounds; and top-gallant mast half the length of top-mast.

Diameter at the partners, one inch to every yard of the length from heel to hounds; top-mast $\frac{2}{3}$ of diameter at partners; and top-gallant mast $\frac{2}{3}$ of the top-mast.

The proportions of the mizen-mast in three masted polacres may be easily deduced from these dimensions.

Art. XXVII.—*Reply to Art. XI. of "Papers on Naval Architecture," on the Position of the Centre of Effort of the Sails, &c.—By* Mr. Wm. Henwood.

There is an obvious want of agreement between what was stated in Art. 33, Vol. 1, respecting the position of the centre of effort of the sails, when a ship is by the wind, and what the writer of this paper had previously advanced. It was owing to this circumstance, that some remarks on Art. 33, were offered in Art. 41. That the true position of the centre of effort of the sails, when a ship is by the wind, should be thoroughly investigated, whilst a difference of opinion concerning it exists, will be considered of importance by persons conversant with nautical science. Unless this point be known, any calculation to ascertain the effect which will be produced by a change of the situations of a ship's masts, or by an increase or a diminution of the area of her sails, must evidently be made with very little assurance that its accuracy will certainly be verified by experiment. It is equally important that correct notions should be entertained respecting the effect of a variation of the fulness of the fore or the after body of a ship, on the position of the mean direction of the resistance on her bottom. An examination of the reasoning by which Lieut. Carlsund has endeavoured to prove, that when a fluid strikes a surface obliquely, the pressure is greater at the after end than at the foremost, will throw some light on the subject of discussion.

Suppose a particle of imperfectly elastic matter, a, moving with a velocity of 20 feet a second, to strike a perfectly hard

plane *dbg* at *b*, Fig. 40, Pl. 7, at an angle *abd*=30° Let the force of compression : the force of elasticity :: 2 : 1; resolve *ab* (=20 feet,) into *ad*, and *db*; *ad* perpendicular to the plane; and suppose the force destroyed at *b*, by the friction and adhesion against the plane, to be one-sixth of *bd*. The velocity of *a*, after impact, in the direction *bc*, will be 15,3 feet a second[1]; and the angle *cbg* will be = 19° 7′. If a new particle *a′*, moving in *a′c*, parallel to *ab*, with a velocity of 20 feet a second, meets the particle *a* at *c*; if the particles are supposed to be spherical and indefinitely small, the velocity of *a*, after impact at *c*, will be 17,7 feet a second in the direction *cg*, inclined to *dg*, at an angle of 20° 37′. It hence appears the particle *a* would be repulsed towards the plane by the new particle *a*,, with a less force, and under a less angle than at *b*; or exactly the contrary to the result of Lieut. Carlsund's reasoning.

It may be observed, that Lieut. Carlsund has said nothing respecting the effect produced by the wind on the fore side of a sail; nor of the manner in which the action of the wind on a sail is affected by the progressive motion of the ship. It was remarked in Art. 7, Vol. 1, that the rush of the air across the ship, may produce a diminution of pressure on the foreside of a sail, near the weather leech, which is not the case in the vicinity of the lee leech. To illustrate this remark, let the direction of the wind *ab*, be inclined at an angle of 70° to *lw*, the course of the ship; and let the sail *eor*, make an angle of 30° with the direction of the wind. Suppose the velocity of the wind to be 20 feet a second; and that "a ship can then just carry her top-gallant sails," the velocity of the ship may be assumed to be 10 feet a second. Whilst a particle of air *e*, moves from *e* to *x* = 20 feet, the point *o*, of the sail, is carried from *o* to *z* = 10 feet; and a pressure is produced at *o* by the line of particles *ox*, = about 15 feet, being driven 10 feet forward by the point *o* of the sail. The particle *e*, if the sail was stationary, would move in the line *exf*; but as the air contained between the lines *ef* and *er*, is pressed forward as the ship moves a-head, the particle *e* must move in a curve line *esv*; being deflectea

[1] These results, and those which follow, may easily be verified by persons acquainted with the principles of mechanics.

towards the sail at *r*, by the air which escapes from the head sails. In this manner, it is conceived, the pressure of the air on the fore side of a sail becomes greatest in the vicinity of the lee leech; and as it is obvious there is no pressure on the fore side of the sail *er*, at the point *e*; the pressure of the air on the fore side of the sail, must increase gradually from the weather side to the lee side.

To show in what manner the motion of a ship affects the action of the wind on the aft side of a sail, let *b h* be parallel to *l w*, and = 10 feet; let *h k* be perpendicular to *a b k*; and suppose the point *b* of the sail, to have moved from *h* to *b*, whilst a particle of air, *a*, has moved from *a* to *b*. Resolve *h b* into *h k* and *k b*; *b k* represents the velocity with which the point *b* of the sail, is carried in the direction of *k a*; and as *k b* (= cos. 70° to radius = 10,) is = 3,42 feet; the velocity with which the particle *a* will meet the sail, will be 23,42 feet a second. Retaining the foregoing hypotheses, respecting the ratio of the force of compression to that of elasticity, and the loss of velocity from the friction and adhesion against the surface; the particle *a* will be reflected in a direction *bc*, with a velocity of 17,3 feet a second at an angle *c b o*, =8° 48'. Suppose *b c* = 17,3 feet, and a new particle *a'*, moving at the rate of 20 feet a second, to meet it at *c*; the particle *a* will be repulsed towards the surface by the new particle *a'*, with a velocity of 18,6 feet a second, in a direction *cg*, inclined to the sail *e r*, at an angle of 21° 26'. The particle *a*, at the end of one second from the impact at *c*, will be at the distance of 22,8 feet, in the direction of its motion, from the sail *er*; and as the velocity of the sail, estimated in the same direction, will be 17,7 feet a second, the particle *a* will approach the sail with a velocity of only ,9 of a foot a second; in the direction of its motion. Hence the motion of a ship has a tendency to increase the force with which the particles of air strike on the aft side of a sail near the weather leech, and to diminish very considerably the force with which they strike farther to leeward. In other words, the pressure of the wind on the aft side of a sail, must diminish gradually from the weather side to the lee side; and since it has been shown that the pressure on the fore side of a sail must increase gradually from

the weather side to the lee side, *a fortiori*, the effective action of the wind on a sail must be gradually diminished from the weather side to the lee side.

This conclusion is in perfect accordance with what was stated in Art. 7, Vol. 1, as matter of fact—that when a ship is by the wind, the tension of the weather braces is always greater than that of the lee braces. It is also found in practice, that when the force of the wind is too great for the strength of the top-sail sheets, it is almost invariably the case that the weather top-sail sheets are carried away, whilst the lee sheets are not. Other facts might be adduced, but it is sufficient to repeat what was stated in the article just referred to—that it has been found by experiment that a plane surface which is acted on by a fluid in an oblique direction, always endeavours to assume a position perpendicular to the line of action. These facts, together with the foregoing reasoning, appear to establish the principle, that when a ship is by the wind, the centre of effort of each sail, is situated to windward of its centre of gravity; and consequently, the common centre of effort of all the sails, must be situated to windward of their common centre of gravity.

This principle is contrary to the common notion on the subject; and it is at variance with some observations in Art. 16. In what manner it affects one of the conclusions of the justly celebrated naval architect, Chapman, in his "Treatise on Ship-building," was pointed out in Art. 22, Vol. 1, of this publication.

It may here be remarked, that the statement in Art. 11, "that the curvature of the sails brings the centre of gravity of each sail further aft in strong winds, is in consequence of the influence of greater angles of incidence towards increasing the resistance,"—cannot be understood, and cannot, therefore, be assented to "by any one, who has not tried to make a theory in his own way, requiring innovations in the laws of nature."

The validity of Lieut. Carlsund's proposition, that "the common notion that a full fore body carries the mean resistance farther aft, is not true in general," is not "thought evident to any one bestowing attention on the subject." In the proof given by Euler, that the mean resistance of a rectangle moving in a fluid, is farther aft than that of a rhomboid, *of the same length,*

the resistance on the foremost end of the rectangle is supposed to have no effect to turn the vessel: and in accordance with this supposition, Lieutenant Carlsund, has asserted, that "the foremost side of the rectangle has no effect towards turning the vessel." It may be asked, if the foremost side, or, the resistance on it, has no effect towards turning the vessel, which side has? If the body A B C D E Fig. 19, Pl. 3, be moving in a fluid, in the direction F G, it is well known, from experiment, that the resistance on the surface A B, will tend to turn it into a position perpendicular to F G: and the resistance on B C, will tend to turn this surface also at right angles to F G. Accordingly, the mean direction of the resistance on A B, passes between the points B and F; and that on B C, between B and H. It is not obvious that the resistance on A B, would have less effect to turn the vessel to leeward, than that on B C, to turn it to windward: because the resistance on A B, multiplied by the distance from F to the point where the mean direction of the resistance on A B intersects A B, might possibly be greater than the resistance on B C, multiplied by the distance from H to the point where the mean direction of the resistance on B C intersects B C, *plus* the resistance on B C multiplied by the distance of K from the centre of gravity of the vessel. In the same manner the mean direction of the resistance on the side F C, of the rhomboid E F C D, passes nearer to F than to C; and that on F E, passes nearer to F, than to E: and the resistance on F C, must have a much greater effect to turn the rhomboid to windward, than that on F E can have to turn it to leeward. Lieutenant Carlsund has therefore very incautiously asserted, that "the foremost end of the rectangle has no effect towards turning the vessel;" and that "the fuller fore body E A B C brings the mean resistance further forward than the sharper one E F C;" and he has not yet proved that "the common notion," above mentioned, "is not true in general."

If the writer is not much mistaken, Lieutenant Carlsund's investigation of the nature of the curve in which the expression of the ardency is a maximum, proves more than he intended. He has shown that the radius of curvature of the curve A B, at the point B, Fig. 22, Pl. 3, is finite, and equal to C B; and

that the radius of curvature at the point A is infinite. Now, in a ship with a full bow, the radii of curvature of most, if not all, of the horizontal sections of the bottom, at the place of the greatest breadth of the ship, are infinite: and the radii of curvature of these sections are minima, at, or near, their foremost extremities. On the contrary, in a ship which has a sharp bow, a considerable number of the horizontal sections of the bottom, have greater curvature in midships than towards the fore and after ends, where these sections are nearly straight. The radii of curvature of these sections therefore, are maxima at, or near their extremities, and minima in midships. If these observations are just, as the writer believes, the very description of curve in which Lieutenant Carlsund has proved that the expression of the ardency is a maximum; and which curve he singularly enough says, "is not very sharp with respect to the axis," is obviously the distinguishing characteristic of a vessel with a very sharp bow. Lieutenant Carlsund, instead of having demonstrated the contrary, has proved with mathematical precision that "the sharpness of a ship forward, abstractedly considered, must always have the effect of augmenting the ardency." This, if not a very "valuable," is certainly not an unimportant "result for the improvement of Naval Architecture;" and it is a result which can "be proved to agree with our present experience."

By referring to the table on page 222, it will be seen that the masts of Swedish ships are usually placed much farther aft than the masts of English ships, of corresponding dimensions. The distinguishing difference between Swedish and English ships is, that the former have "full fore bodies and extremely fine after bodies;" whilst the latter, in many instances, have sharp fore bodies, and very full after bodies; and in general, are less full forward, and less sharp abaft, than ships of Swedish construction. Now, if a full fore body does not carry the mean direction of the resistance of the water farther aft, would not the masts of Swedish ships have been required to be placed considerably farther forward than they have been; or else the masts of English ships have been required to be placed considerably farther aft? The writer of Art. 16, has very clearly shown the propriety of placing the masts of those ships of the

British Navy which are similar in form to Swedish ships, farther aft than the masts of those which are similar in form to the old French ships.

Another proof from "experience," is furnished by the well-known fact mentioned by Lieutenant Carlsund, in Art. 33, Vol. I;—that "an addition to the gripe," which is a virtual increase of the sharpness of the fore body, "makes a vessel more ardent."

In the article just referred to, it was truly remarked, that "if the after part of the keel, or the stern, were increased, it would lessen the ardency." Lieutenant Carlsund however appears to have changed his opinion since he wrote Art. 33, Vol. I: he has stated in Art. 11, "that the shape of the after body has a considerable influence upon the ardency, which is increased by making that part of the ship sharper." The writer freely confesses his utter inability to reconcile these statements one with the other. He is equally unable to understand the following assertion, that if "a plane surface invariably meets with more resistance than a convex one;" and if, in consequence thereof, "the sharpness of a ship forward, abstractedly considered, must always have the effect of augmenting the ardency;" so must it also be admitted, that a sharper ship meets with a greater resistance than a full one. The reader will not require to be reminded that the resistance on the plane side of a solid hemisphere, is greater than the resistance on the surface of a globe of the same diameter; that it is the lateral resistance on the lee bow of a ship, and not the direct resistance, which makes her ardent; and that a ship with a sharp bow experiences greater lateral resistance than one with a full bow. "An addition to the gripe" causes an increase of the lateral resistance of the fore body.

Lieutenant Carlsund has referred to "the reasoning which, in Art. 33, precedes the mentioning of a frigate being very weatherly," and has said that "by applying this reasoning, the apparent contradiction in the instance which has been referred to (in Art. 41,) vanishes." If the reader is disposed to satisfy himself respecting the truth of this declaration, he is desired to peruse the last paragraph on page 396, Vol. I. He will then decide whether what was said in Art. 41, "does not affect the

validity of the statements in Art. 33." It was never doubted that the frigate in question was "uncommonly weatherly and ardent:" the fact, that the masts of Swedish ships are usually placed very far aft, in comparison with those of British ships, may, in a great measure, account for this circumstance.

It will now be proper to notice an observation in Art. 11, p. 168. Having obtained an expression for the total momentum which tends to turn the surface A B, Fig. 20, Pl. 3; on the supposition that the friction has no effect to turn the vessel; Lieutenant Carlsund has remarked, "that on the lee side and the foremost part of the vessel, where the impulse is greatest, in consequence of the greater angles of incidence, the friction has a tendency to counteract the turning, which is greater in sharp vessels than in full ones, owing to the difference between their respective angles of incidence: hence it appears to follow, that the ardency calculated in this way will be proportionably less in the fuller vessel than in the sharper one, than it would have been if the friction had been considered." This is true, if the water passes with greater difficulty towards the stern round a sharp bow, than round a full one. But since, as Lieutenant Carlsund appears to think, "a great burthen and fast sailing" cannot "easily be united," there must be greater resistance to the motion of a ship in the direction of her course, and consequently greater friction and adhesion, when the bow is full, than when it is sharp. Hence "it appears to follow, that the ardency will be proportionably "*greater* in the fuller vessel than in the sharper one, than it would have been if the friction had been considered."

It may not in this place be improper to observe, that, in conformity with the reasoning in Art. 22, Vol. 1, the motion of the water round the bow of a ship towards the stern, must be considered as relative with respect to the motion of the ship. That the water afore the greatest breadth is driven ahead, or has an absolute motion in the same direction as the ship, as Chapman has stated, there appears no reason to question. And that it has a relative motion or velocity towards the stern, in consequence of the greater velocity of the ship, is equally certain. The friction of the particles of water on the bow, in passing round it, must depend both on this relative

velocity, and on the force with which the particles are pressed against the bow. The conclusion derived from the observations in the article referred to, "that the whole of the water contiguous to a ship, must have a motion in the same direction as the ship," may perhaps be strengthened by remarking, that when a ship is moved forward, from one point of space to another, for instance, the distance of a foot, in the twentieth part of a second,—it seems unreasonable to suppose that the vacuity, or the partially void space formed all round the after body of the ship, can be filled by particles of fluid passing from midships towards the stern along the sides of the vessel: it seems impossible, but to believe that at every instant whilst a ship is in motion, the particles of fluid surrounding the whole surface of the after body, must be impelled in the directions of the shortest lines in which they can move towards the bottom of the ship, by the continual pressure of the surrounding fluid.

These remarks appear to show, that with our present limited knowledge of the subject, it must be difficult, to say the least, to compare the resistances of the water on two vessels of different forms. Lieutenant Carlsund however says, "it is extremely easy to measure or estimate the effects produced by the differences of forms, when a measure of these differences and the corresponding effects can be given for a determined number of bodies." If the writer does not misunderstand this assertion, it amounts to this; that when a measure of the differences of form, and a measure of the corresponding effects can be given, it is extremely easy to measure the effects produced: or, it is extremely easy to measure when a measure can be given. The question to be decided is, whether it can be ascertained that of two ships, of the same length, breadth, depth, and displacement, dissimilar in form, and having the mean directions of the resistances of the wind on the sails, and of the water on the bottom directly opposite, one would sail faster, or be more weatherly than the other. If this can be done, it is something which the writer admits he is not aware of; but if this cannot be done, Lieutenant Carlsund's remarks on the subject are altogether unsupported.

If the reader will refer to Art. 41, he will find it is not stated, that the velocity of a ship increases with the force of the wind,

when the vessel is close hauled, as Lieutenant Carlsund appears to intimate; although, in fact, it generally does, when the wind does not increase so much as to render it expedient to take in sail. It was stated, that "in proportion as the velocity with which a ship moves ahead increases; and, according as the water acts with greater force on the lee bow through the pitching of the ship; so will the mean direction of the resistance on the bottom pass farther forward." It was not supposed the mean direction of the resistance on the bottom would pass farther forward, unless an increase of velocity, or the pitching of the ship, caused the water to act with increased force on the lee bow. The assertion relative to the following remarks, that "if both these conjectures are right, it is a proof that two exactly opposite causes give the same result;" is unaccountably erroneous. One of those conjectures, in Art. 41, was, that the "uncommon" ardency of Chapman's frigate, which had "a very full fore body," might have been occasioned by her having weights placed too near the bow; which would cause her to pitch heavily. The other conjecture was, that the reason why some ships with full bows, which carry a weather helm in smooth water, carry a lee helm when the sea is rough, may perhaps be, that the weights are not placed so far forward, as it is absolutely necessary they should be, in order to make the ships pitch sufficiently heavily to prevent waves which meet their bows from turning them to leeward. In the one case, the consequence of too many weights being placed towards the ends of a ship would be, that whenever the ship pitched, her head would be raised slowly, and the water would act with comparatively great effect on the lee bow to turn the ship to the wind. In the other case, when the weights are situated too near midships, every time the ship pitches, her head is raised suddenly, and the waves act with comparatively great effect on the weather bow to drive the ship to leeward.

What has been said respecting the parabolic method of constructing ships is unconnected with the subject of the above disquisition. It is admitted that the concluding sentence, but that only, of Art. 41, Vol. 1, expresses too much. But it was never said by the writer, that small dissimilarities of shape "are not the fundamental parts of the science of naval archi-

tecture," although they certainly are not; for with no sort of propriety whatever can small dissimilarities of shape be said to be "parts of the science of naval architecture." By the phrase, "the fundamental part of the science of naval architecture," in Art. 41, was meant, the investigation of that particular form of a ship which would experience the least resistance when moving in the water.

Art. XXVIII.—*Proposed Improvement in the Artificial Horizon, by* Captain Hendry, R. N.

(*To the Editor of Papers on Naval Architecture.*)

Gentlemen,

Having made an alteration in the artificial horizon now in use, which I hope will be found an improvement, I beg leave to offer an account of it for insertion in your work. Fig. 41 represents a vertical section of the instrument: A B C D is the frame of wood; E E the trough; F F the place of the quicksilver; D H A the brass frame of the glasses fixed down upon leather; G the pushing screw; opposite to G is the cock through which the quicksilver flows into E E. The advantages of this plan are, that the quicksilver is not exposed to the air, and therefore will remain much longer clean; that from the frame of the glasses being fixed down upon leather, the quicksilver cannot be spilt by accident; and that the instrument can be more readily prepared by the observer, as the quicksilver is contained under the glasses, and flows into the trough by the action of a pushing screw, passing through a cock which is air-tight.

I am, gentlemen, your obedient servant,

Wm. Hendry.

Buckland, near Portsmouth, June 10*th*, 1829.

Art. XXIX.—*Observations on the Forces which act on a Ship when in Motion, as they affect the Height of the Centre of Effort of the Sails, with a view to determining the correct Proportions of the Masts and Yards.*

In Art. 16, Vol. 2, the method of finding the horizontal distance of the centre of effort of the sails, either before or abaft the centre of gravity of the ship, was explained, and an endeavour was also made to describe the effect which the action of the water on the hull, and of the wind on the sails, would have, under various circumstances, on the relative positions of these points: and also to show the necessity of regulating the trim of the ship according to the state of wind and sea, that the most advantageous proportionate distance may be preserved between them. It remains to examine the principles on which the determination of the vertical heights of the centre of effort of the sails above the centre of gravity of the ship depends; and also by the aid of these principles, to show that this problem in the "Theory of Ships," though it may be classed among those of which the "solution resolves itself to laws of nature, which are yet imperfectly developed," may be solved by induction from experiment; and that sufficient data may by this means be obtained, to render the abstract principles of science, on which it depends, practically available; so as to overcome the difficulties which at present oppose themselves to the perfecting of one of the most important elements of construction, the size and proportions of the masts and yards. Preliminary to this, it will be necessary to recapitulate some of those principles of construction, on which the subsequent remarks will depend.

It is a well known principle in Hydrostatics, that a body supported on a fluid, displaces a quantity of the fluid equal in weight to itself; and therefore that a vessel floating on the water, will be subjected to a vertical pressure acting upwards equal to its own weight. It is also known, that the resultant of this vertical pressure upwards, must always act at the centre

of gravity of that part of the body which is immersed, considered as homogeneous; and this equilibrium between the vertical pressure of the water acting upwards, at the centre of gravity of the displacement, and the weight acting downwards, at the centre of gravity of the ship, will remain unchanged, under all circumstances of rest or motion, while the vessel is supported by the fluid. As long as the ship is acted upon by no other force than that of gravity, the direction of the resultant of the vertical pressure upwards, must be directly opposed to that of the resultant of the weight acting downwards; it will therefore pass through the centre of gravity of the ship. But when, from the operation of any other cause, as the force of the wind, the ship is inclined from its vertical position, its centre of gravity becomes the centre of rotation; and since, by the inclination, a portion of that part of the ship's body, to leeward of the centre of gravity, is immersed in the water, while an equal part of that to windward is emerged, the centre of gravity of the displacement will be carried to leeward of the centre of gravity of the ship; and, consequently, the direction of the resultant of the vertical pressure upwards, which passes through that point, will also pass to leeward of the centre of gravity of the ship: and the moment of the force exerted by the vertical pressure to resist the inclination, will be measured by the perpendicular distance from the centre of gravity to the direction of the resultant. This moment is usually called the moment of stability, but is more properly termed the moment of hydrostatical stability, as being dependent on the laws of the equilibrium of fluids. But if the force, which has been described as inclining the ship round its centre of gravity, also communicates motion to the system, another moment of stability will be generated by the resistance which the water opposes to the motion. This resistance, as has been before explained, may be supposed to act in a resultant, the direction of which will, of course, depend on the form of the vessel: now, if the form be such, that the direction of this resultant will pass above the centre of gravity of the ship, its moment, estimated from that centre of gravity, will act in conjunction with the moment of hydrostatical stability, before described, and will diminish the inclination: a contrary effect will ensue if this re-

sultant passes below the centre of gravity. Now, if the moment of this force to diminish the inclination were equal to the moment of the force which acts to produce it, the ship would remain in a vertical position; but if it be not equal to it, the inclination will be caused by the action of the excess of the latter force over the former, and the ship will revolve until this part of the inclining force is destroyed by the moment of hydrostatical stability, which will be generated by the inclination. The moment of stability resulting from this cause may be called the moment of hydrodynamical stability, as being dependent on the motion of the body in the fluid, that is, on the relative motion of the fluid. This does not agree with the usual definition of hydrodynamical stability, as that involves the elements of the hydrostatical stability in its terms. (See Art. X., Vol. 2.) But it is thought, that by keeping each moment of stability distinct, by referring it wholly to its own generators, the explanation of the principles on which the height of the centre of effort of the sails depends, may be divested of some obscurity.

Now when, by the action of the wind on the sails, motion is communicated to a vessel from a state of rest, at first the effort of the wind on the sails is much greater than that of the water on the hull; and, by the effect of the excess, the velocity of the vessel is accelerated; but the velocity with which the wind acts on the sails is diminished in proportion as the velocity of the vessel is increased; therefore, also, the force with which it acts on them is gradually lessened; but as the velocity of the vessel increases, the resistance the water opposes to its motion is also increased; consequently the two forces, the effort of the wind on the sails, and the resistance of the water on the hull, will ultimately become equal to each other; and as they act in opposite directions, the vessel will, by the laws of motion, continue to move uniformly in the direction of its course, with the last acquired velocity; and this velocity will be in proportion to the moving force, that is, to the force of the wind and the area of sail exposed to its action; or, if the force of the wind be supposed constant, will be in proportion to the area of the sail.

From what has been before said, it is evident that the mo-

ment of sail must be in proportion to the stability of the ship; and since the velocity will be in proportion to the area of sail exposed to the action of the wind, the height of the centre of effort of the sail should be determined from the consideration of acquiring the greatest effective area of sail of which the powers of the ship will admit.

Bouguer, from reasoning on the facts which have been explained, (that when a ship has acquired an uniform velocity in any direction, the action of the wind on the sails to propel her in that direction, becomes equal to the resistance opposed to her motion by the water; and, that the moment of the resistance, calculated from the centre of gravity, or of rotation, that is, the moment of hydrodynamical stability, subtracted from the moment of the action of the wind on the sails, estimated from the same point, will give the force by which the ship is inclined,) conceived the idea that the sails of a vessel might be so disposed that she should maintain the same vertical position when under sail as when at anchor. This he proposed to effect by adjusting the sail in such a manner that its centre of effort should be situated in a point, which he has named the "*point velique*," and which he describes as being such, that when the centre of effort of the sails coincides with this point, the moment of the force of the wind to incline the ship will be wholly destroyed by the moment of hydrodynamical stability. But such an arrangement of the sail is not practically applicable to the cases in which the direction of the action of the force of the wind is oblique to that of the course of the vessel; for, from the small proportion which the breadth of a vessel bears to her length, the moment of hydrodynamical stability will, under these circumstances, be less than when the directions of the wind and of the ship's course coincide; while the resultant of the effort of the wind will act at the same height above the centre of gravity of the ship in either case; therefore, Bouguer only insists that since the moment of the hydrodynamical stability cannot, consistently with other circumstances, be made to destroy the whole of the effort of the wind to incline the ship, care should be taken that these two forces should be so proportioned to each other, that a sufficient moment of hydrostatical stability may be acquired, without too great an inclination of the ship,

to resist the excess of the moment of the wind on the sails over the moment of hydrodynamical stability.

But when the direction of the wind coincides with that of the course of the vessel, it is of great importance that the change from a state of rest to one of motion, or rather, from one velocity to another, should be performed without any longitudinal inclination towards either extremity, and that the vessel should preserve that seat in the water which has been determined as most advantageous with reference to the longitudinal position of the centre of effort of the sails.

The course of reasoning which Bouguer has pursued to determine the position of this point, involves suppositions which are at variance with the facts attendant on a vessel's motion through the water; and, therefore, the conclusion at which he arrives is erroneous; still, as an elucidation of the principle, his method may be advantageously explained.

He supposes D H (Fig. 42,) to be the direction of the resultant of the direct and vertical resistances experienced by the fore part of the vessel, A E F B, moving in the direction A B; and the line S K to be the direction of the resultant of the whole force of the wind acting on the sails; let it meet D H in N; now, since when the ship has acquired an uniform velocity, the forces which oppose the motion are equal to those which produce it; and as these forces act horizontally, and destroy each other, the forces which remain must be vertical. Take N R and N P to represent, in quantity and direction, the force of the water on the bows, and of the wind on the sails; then complete the parallelogram N R T P, and join N T; N T will represent, in quantity and direction, the force remaining after those parts of the forces, N R and N P, which are equal and opposite, are destroyed; and, therefore, N T will act in a vertical direction, to lift the ship. But though this will be the direction of the action of N T on the vessel, its effect may also be to produce a rotary motion round her centre of gravity. This will depend on the position of the point N, the intersection of S K and D H. If we suppose the direction D H to be constant in position, and S K to vary according to the height of the sails, we shall see that when the masts and sails are high, the direction S K will cut the direction D H at a

point near the stern; and, therefore, the action of the force N T taking place so near one extremity of the vessel, and on one side of the centre of gravity, will tend to immerse the extremity on the opposite side of that point: on the contrary, if the masts and sails are low, the direction S K will intersect the direction D H more towards the bows of the ship; and the action of N T, being before the centre of gravity, will raise the fore and immerse the after part; and this inclination will continue, until the force which causes it, is destroyed by the moment of the hydrostatical stability generated by the inclination. From this, Bouguer concludes, that it is only when the masting is of such a height that the direction S K intersects D H at a point at some mean distance between the bows and stern, and at which neither of these effects will be produced, that the ship will have no tendency to longitudinal oscillation, and the only effect of the force N T will be to lessen the part of the ship which is immersed in the water when she is at rest; and this point he has called the "*point velique.*" Bouguer determines the position of this "*point velique*" in the following manner:—From *r*, the centre of gravity of the load water section, as being nearly coincident with the centre of gravity of the lamina, A B *b a*, of the vessel which is lifted by the action of the force N T, the vertical line V T is drawn; and the point N, in which it intersects the direction of the resultant of the resistance of the water to the bows, will be the point through which the horizontal line S K, representing the direction of the action of the wind on the sails, should pass, in order that the ship may move in the direction of its course without depression of either extremity. In order to prove that this will be the case, he supposes the displacement, A B F E, of the ship, to be made up of the two homogeneous parts A B *b a*, and *a b* F E; and therefore, when the ship is only subjected to the vertical pressure upwards of the fluid, these parts will have their common centre of gravity, which will be the centre of gravity of the displacement, in the same vertical plane with the centre of gravity of the ship. The horizontal distances of *r* and *w*, the centres of gravity of the homogeneous parts, A B *b a* and *a b* F E, from the vertical section in which the centres of gravity of the ship and of the displacement are, will be inversely as those parts;

but when, by the action of the force N T at *r*, the displacement is diminished by the quantity A B *b a*, the vertical pressure upwards will be diminished by that same quantity, and will act at *w*, the centre of gravity of the new displacement *a b* F E, with a force equal to *a b* F E; therefore the forces being inversely proportionate to the distances of their action from the common centre of gravity of the ship, and both acting upwards, in a vertical direction, will maintain the ship in equilibrio round that centre of gravity.

This reasoning of Bouguer on the position of the point N, is incorrect in its application to practice. It depends on the supposed fact, that when, by the force of the wind, motion is communicated to the vessel, she will rise in the water from the effect of the action of the force N T, and the water line A B will become *a b*; the displacement being diminished by the quantity A B *a b*. It is not enough to satisfy the conditions of Bouguer's reasoning, that N T should exert an effort at *r* equal to diminishing the displacement by the quantity A B *b a*; for, unless the diminution of the displacement actually takes place, the position of its centre of gravity cannot be affected in the manner assumed in the reasoning, but will continue in the vertical section passing through the centre of gravity of the ship; and then, by the action of the force N T at *r*, the ship will revolve round the centre of gravity *g*, until, by the motion of the centre of gravity of the displacement, incidental to the revolution, a moment of hydrostatical stability is generated equal to the moment of N T to incline the ship. Now it is proved, from experiment, as has been shown in Articles 16 and 20, Vol. 1, that the displacement is actually greater when a ship is in motion than when she is at rest; therefore, reasoning on the supposition of its diminution is inapplicable to practice. There would be an alteration in the position of the centre of gravity of the displacement, resulting from this increase, which might either act in opposition to, or with, the effect of N T, to incline the ship, according to the relative form of the body above the original water line.

But it is evident that the principal error made by Bouguer, throughout the investigation of the position of his "*point velique*," is, that it is conducted with reference only to the re-

sultant of the positive resistances which the vessel experiences, instead of to the resultant of both positive and negative resistances. Chapman, while he adopts Bouguer's views on the existence of some limit to the situation of the centre of effort of the sails above the centre of gravity of the ship, has avoided this error, and has investigated its position from the data of the total resistance experienced by the ship: he first determines the quantity and direction of the mean resultant of both the positive and negative resistances of the water; then, since the force of the wind must be equal to the resistance of the water opposed to it, if the directions of the resultants of these two forces were exactly opposed to each other, their moments, estimated from the centre of gravity of the ship, would be equal; and, consequently, the force of the wind would have no effect in making the ship revolve round its centre of gravity; therefore, if the surface of the sail was perpendicular to the resultant of the direct and vertical resistances experienced by the ship, there would be no limit, arising from these considerations, to the height at which the centre of effort of the sails might be placed; for whatever might be its position in the line of direction of the resultant of the resistances of the water, the moments, estimated from the centre of gravity of the ship, would be constantly equal, since the perpendicular distance between that point and the directions of the actions of the forces would remain constant, however the force of the wind, and, consequently, the resistance of the water, might be increased or diminished. But since the directions of the wind, and of the course of the vessel, are both horizontal, and the sails are placed nearly at right angles to the horizon, the action of the force of the wind, and its moment round the centre of gravity of the ship, to counteract the moment of the resistance of the water, must be estimated in a horizontal direction; and, consequently, the height of the centre of effort of the wind on the sails, must be measured on a vertical line drawn from the centre of gravity of the ship, and must be such, that the horizontal moment of the wind, shall be equal to its moment, estimated under the supposition that its action is in a direction opposed to that of the resultant of the resistances of the water, it will then have no tendency to depress either extremity of the vessel.

Chapman's investigation is as follows. Suppose D F and E C, (Fig. 44,) to represent, respectively, both in quantity and direction, the resultants of the direct and vertical resistances against the fore and after parts of the vessel, produce D F and C E to intersect each other in B; then on D B produced, take B V = D F, and on B C take B I = E C, complete the parallelogram V B I H, and B H will represent, in quantity and direction, the resultant of the whole of the direct and vertical resistances against the fore and after parts of the ship; and B H, multiplied into G M, G M being drawn from the centre of gravity G of the ship, perpendicular to B H produced, will represent its moment to make the ship revolve round its centre of gravity. The centre of effort of the sails must therefore be at such a height that the moment of the wind, estimated from the centre of gravity of the ship, may be equal to this moment. If H M represents the line of direction of the effort of the wind on the sails, the force of the wind, acting in that direction, will be represented in quantity by H B; but as the action of the wind is horizontal, and is equal to the horizontal effort of the water, if B H be resolved into B N and N H, then B N represents, in quantity and direction, the horizontal resistance of the water, and N B, in the same manner, represents the horizontal effort of the wind; and if G O be drawn from G, perpendicular to the horizon, meeting H B in O, we have, from similar triangles, H B N and O G M, $NB \times GO = HB \times GM$; that is, O, the point in which a vertical line, passing through the centre of gravity of the ship, intersects the direction of the resultant of the resistances of the water against the fore and after parts of the ship, is the correct height at which the centre of effort of the sails should be placed, that the ship's horizontal water line, when she has acquired an uniform velocity, may not be affected by any change in the force of the wind.

This point O does not fulfil the conditions of Bouguer's point of sail, as it only determines the position of the centre of effort of the sail, as to height above the centre of gravity of the ship; for the moment of sail acting in a horizontal direction estimated above that centre of gravity, will be the same at whatever point in a horizontal line, passing through O, the centre of effort may be placed; therefore this point O may be more pro-

perly called the height of sail. The position of the centre of effort of the sails in a horizontal line at this height of sail, will depend on the considerations explained in the article which was referred to at the beginning of this paper. It may therefore differ very considerably from that determined by Bouguer, not only in its vertical, but in its horizontal position.

From this investigation of Chapman's, it evidently appears, that unless B H coincides with N B; that is, unless the resultant of the resistances of the water is horizontal, there will be a force N H or H N, acting in a vertical direction, either upwards or downwards, at the centre of gravity of the ship, according as the positive or negative vertical resistances are the greater, for this force acting in a vertical direction, cannot be derived from the direct resistances, which act horizontally; and since the whole force of the wind acts in a horizontal direction, and is destroyed by the horizontal effort of the water, no part of its force can be employed in a vertical direction affecting the action of H N or N H; this force will therefore act to increase or diminish the displacement of the ship when in motion, accordingly as the negative or positive vertical resistances are the greater, that is, the quantity by which the displacement would be increased by the diminution of the vertical pressure upwards, incidental to the motion of the vessel, will be diminished by the action of the force N H; but unless N H is greater than the diminution of the vertical pressure upwards, it will have no effect on the position of the centre of gravity of the displacement and, therefore, none on the longitudinal inclination of the ship. The force H N, acting in conjunction with the diminution of the vertical pressure upwards, will affect the position of the centre of gravity of the displacement, in the same manner as that affects it, that is, dependent on the relative form of the body above the water. Therefore, in this case, the ship may have a slight tendency to longitudinal oscillation, even though the centre of effort of the sails is placed at the height of sail, as determined by Chapman; but this will not affect the correctness of Chapman's principle; and a ship may be easily constructed with such a form at the parts about the surface of the water, that this inconvenience will not occur.

Now, if we suppose B V and B I to be given in position, the force N H, or H N, will depend, in quantity and direction, on the proportion between B V and B I, that is, on the proportion of D F to E C, and B V : B I :: sine H B I : sine V B H. Now when B H coincides with N B, or when the direction B H of the resultant of the water is horizontal, the force N H, or H N, vanishes, therefore, if we suppose H B to coincide with B N, then H B is parallel to C D; and the angle V B H will be equal to the angle B D C; and the angle B C D will equal the angle H B C=V H B. Now V H : V B :: sin. V B H : sin. V H B :: sin. B D C : sin. B C D :: B C : B D; and since V H=B I=E C and B V=D F; E C : D F :: sin. B D C : sin. B C D, consequently we have, that the positive and negative vertical resistances are equal to one another, and the direction of the resultant of the resistances of the water is horizontal, when the resultant of the direct and vertical resistances of the water on the bows of the vessel, is to the resultant of the direct and vertical resistances on the stern, inversely as the angles which the directions of these resultants make with a horizontal line.

The extremities of a vessel of the usual form may, for the purpose of determining the proportion between the direct and vertical resistances which they experience, be considered as planes moving obliquely in a fluid, and consequently, the proportions between the direct and vertical resistances, will depend on the angle of inclination, which these extremities make with the direction of the vessel's motion, that is, with a horizontal line; and the sum of the direct resistances on either extremity, will be to the sum of the vertical, as the sine to the cosine, of the angle of inclination, consequently as long as the inclinations of the bow and stern to a horizontal line remain unchanged, this proportion between the direct and vertical resistances experienced by those parts, respectively, that is, the proportion of D K to K F, and of L C to E L, will be invariable; and therefore, as far as these considerations are involved, the directions of the resultants D F and E C, will remain constant, whatever alteration may take place in their relative proportion to each other, arising from any increase or diminution in the velocity of the vessel.

Since, when the direction of the resultant of the water is horizontal, EC : DF :: sin. BDC : sin. BCD, then EC.sin. BCD=DF.sin. BDC; now let us suppose the proportion of DF to EC to be altered, so that EC.sin. BCD will be greater than DF.sin. BDC, that is, let us suppose the comparative proportion of DF to EC to be increased.

Produce DV to P, and make BP to BI in the increased proportion of DF to EC, complete the parallelogram BPQI, and draw the diagonal BQ, BQ will represent the direction of the resultant of the resistance of the water, after the alteration of the proportion between DF and EC.

Produce QB to S, then the angle PBQ=the angle DBS, and since BP is parallel to IQ, the angle PBQ is equal to the angle IQB; and the angle IHB is greater than the angle IQB, consequently, the angle DBM, which is equal to the angle IHB, is greater than the angle IQB; that is, the angle DBM is greater than the angle DBS, and S, the point in which the direction QB cuts the vertical line GO, will be within, or below the point O; therefore GS will be less than GO. If EC, that is, BI, had been increased in proportion to DF or BG, the point S would, in the same manner, have been found to be above the point O. Consequently, from this we may deduce the following general proposition: that, as the proportion which the resultant of the direct and vertical resistances on the bows of a vessel, bears to the resultant of those resistances on the stern, is greater than the proportion which the sine of the angle made by the resultant of the after resistances, with a horizontal line, bears to the sine of the angle made by the resultant of the fore resistances with a horizontal line, the height of sail will be diminished, and as this proportion is diminished, the height of sail will be increased. Now when DF is infinite in comparison with EC, that is, when the negative resistances vanish, BQ will coincide with BP, and the height of sail will be at W, the point in which the vertical line, drawn from the centre of gravity of the ship, will intersect the direction of the resultant of the positive resistances. But if DF vanishes in comparison with EC, BQ will coincide with BI, and the height of sail will be at R, the point in which the vertical line, drawn from the centre of gravity, inter-

sects the line B C. Consequently, the points R and W will be the limits between which the position of the height of sail must be situated. The directions of the resultants of the resistances on the bow and stern being known, the position of this point within these limits, will depend upon the velocity of the ship, in as far as that velocity affects the proportion between these resultants. And since the negative resistance depends on the degree of vacuum which the vessel creates by the velocity of its passage through the water, it will evidently be very inconsiderable, as long as that velocity continues small; in fact, this is found to be the case experimentally, as is also, that after certain limits, this negative resistance increases in a greater ratio than the velocity, we may therefore draw the general conclusion, that the less the velocity of the ship is, the nearer will the height of sail approximate to that of its lowest limit; and, on the contrary, the greater the velocity of the ship, the higher will this point be situated. But as we are not yet sufficiently acquainted with the laws of the motion of fluids, to determine the ratio of the increase or decrease of the positive and negative resistances experienced by bodies in their passage through the water, we cannot ascertain how near the ultimate position of the height of sail, with the greatest velocity which the vessel can acquire, will approximate to the limit which has been assigned to it.

One circumstance which may affect the height of sail remains to be noticed, this is, the deviation of the apparent water line of the ship when in motion, from its horizontal water line, occasioned by the accumulation of fluid at the fore part of the ship, and the depression at the after part, which is incidental to the motion of a body on a fluid, this, of course, will vary in degree, in proportion to the velocity of the ship; now if this addition to one, and diminution of the other, of the resisting surfaces alters the proportions between their respective vertical and direct resistances, the directions of the resultants of the resistances on these surfaces, which depend on these proportions, will also be altered. If the extremities of the vessel were formed by plane surfaces, neither the accumulation or the depression would alter the directions of the resultants of the resistances; since the angles of incidence would be the same for every

part of the surfaces, but as the extremities of the vessel are curved surfaces, the effect produced on the direction of the resultants of their respective resistances, will depend on the relative inclination to the horizon of the curve of that part of the body, beneath the horizontal water line, and of the parts above or below that water line, which will be affected by the accumulation and depression. Since the lower parts of the vessel's body, both forward and abaft, are those which are generally most inclined to the horizon, it is probable that the direction of the resultant of the resistances on the bows, is lowered by the accumulation of the water against them, and that the resultant of the resistances to the stern, is rather raised by the depression of the water at that part; at the same time it must also be observed, that by the effect of the accumulation, the centre of effort, at which the resultant of the resistances against the bows acts, will be raised; while, by the effect of the depression, that of the stern will be lowered.

The position of this point will determine the height above the centre of gravity of the ship, at which the common centre of effort of the sails should be placed, not only when the directions of the wind and of the ship's course coincide with each other, but also, whatever may be the direction of the ship's course with regard to that of the wind; for under all circumstances, that portion of the force of the wind which acts in propelling the ship in the direction of her course, will be subject to the same laws which govern the action of the whole force of the wind, when it acts in that direction.

It is also evident, that it is not only necessary that the centre of effort of the surface of those sails which are usually set, and for which the position of the height of sail is generally recommended to be estimated, should coincide with this point; but also, that when additions are made to the quantity of sail set, care should be taken to preserve the common centre of effort of the whole surface, as nearly at the same height above the centre of gravity of the ship as is possible.

It is frequently observed, that a ship's velocity does not increase or decrease in proportion to the additional quantity of sail set or taken in. It is evident, from the principles which have been explained, that these apparent anomalies must arise

from the mal-position of the centre of effort of the sail, and in fact, it is even possible that the velocity of a ship may be decreased by the addition, and increased by the diminution of sail, if the centre of effort is improperly placed. That this may be more evident, suppose A B (Fig. 43) to be the water line of a ship, when the centre of effort of the sails is situated at the correct height of sail G F, then suppose the disposition of the sails to be so altered that their centre of effort coincides with E, a point situated above the point F, and let $a =$ the force of the wind on the sails, both before and after the alteration, its moment to turn the ship round its centre of gravity G, when its action takes place at the point E, will be equal to $a \, . \, \text{E G}$, and this force will be opposed by the horizontal resistance of the water, also $= a$, acting at the distance F G from the centre of gravity G, therefore $a \, . \, \text{E G} - a \, . \, \text{F G} = a \, . \, \text{E F}$, will be the force exerted by the wind to make the ship revolve round G, its centre of gravity, and immerse the bows; and the inclination will continue from the effect of this action, until the moment of hydrostatical stability, which it will generate, becomes sufficient to counteract it. It should here be observed, that by the difference which the inclination of the ship will make in the angles of incidence of the water on the bows and stern, the correct height of sail, after the inclination, will most probably not coincide with F, but the alteration arising from this circumstance in the position of this point, will depend on the form of the vessel's body.

When the force $a . \text{EF}$ is destroyed, suppose the water line to coincide with CD, then from G draw GH, making with GE the angle EGH equal to the angle of inclination DGB; take GH=GE, then H will be the position of the centre of effort E, of the sail, after the inclination, and GH will represent the inclination of the plane of the sails to the horizon, they having been supposed to be vertical before the inclination. Now from H, draw HM, horizontal, and take MH to represent the whole force of the wind, acting in that direction, at the points H and F; then from M, draw ML perpendicular to GH; and from L draw LK perpendicular to MH; MK will represent the horizontal force of the wind acting to propel the ship in the direction of its course, when the centre of effort of the sails is

at E. Since M H represents the quantity of this force when the centre of effort of the sails is at the true height of sail F, KH will represent that part of the force which is lost by the mal-position of the centre of effort; and KH equals the versed sine of the angle of inclination, to a radius equal to the whole force of the wind: therefore, if the removal of the centre of effort from its correct position at the height F, had been accomplished by an addition to the quantity of sail set, instead of by an alteration in their disposition, unless the increase of MH, the force of the wind, arising from the increase in the area of sail set, is greater than KH, the versed sine of the inclination to the radius MH, and which represents the force lost; the velocity must be diminished, instead of being increased, by the addition to the force of the wind; since its effective force to propel the ship, would be diminished by a quantity equal to the difference between the versed sine of inclination and the increase of the whole force of the wind. Now suppose, that by the mal-position of the centre of effort, at E, the ship is inclined, so that G H is the plane of the sails, it is evident that the quantity of sail may be reduced, until the force of the wind is diminished by a quantity equal to the versed sine of inclination, without diminishing the velocity; if, by this reduction in the quantity of sail, the centre of effort is removed to its correct position at F. This reasoning shows, that in a ship having the centre of effort placed too high above the centre of gravity, the disadvantages of such an adjustment may be lessened by raking the masts, since by that means the loss in the force of the wind may be avoided.

When the centre of effort is above the height of sail, the velocity of the ship will be subject to further decrease from the increase of resistance, which will result from the immersion of the full parts of the body forward, and the consequently greater area of midship section. Also, in the case which has been supposed, of the plane of the sails being vertical before the commencement of the action of the wind, when the longitudinal inclination E G H takes place, a part of the action of the force K L will act to increase the displacement, and consequently the resistance. This disadvantage may also be diminished by raking the masts.

There are other circumstances arising out of the longitudinal inclination of the ship caused by the excess of the moment of the wind on the sails, over the moment of hydrodynamical stability, which are disadvantageous to the good properties of the ship. The equilibrium which ensues between the excess of the moment of the wind, and the moment of hydrostatical stability, which has been described as being generated by the inclination, will not be stable; as every increase or decrease in the force of the wind, will cause an increase or decrease in the moment of stability, which must be obtained by a corresponding change in the inclination; therefore a ship in which the centre of effort is placed above the true height of sail, will be subject to an alteration in her water line at every change in the force of the wind; and it will, owing to this circumstance, not only be impossible to adjust the longitudinal position of the centre of effort to any fixed trim of the ship which may have been found to be advantageous; but it will be equally impossible to determine the best longitudinal position for this point, after the ship is in a state of motion, since her trim will be subject to constant alteration.

If the centre of effort, instead of being supposed to be situated above the true height of sail, be considered to be below that point; the immersion will take place at the after extremity of the ship, from the action of the excess of the moment of the resistance of the water. It must also be observed that there will be this difference in the two cases. When the centre of effort is above the height of sail, at every increase in the force of the wind, the ship will, from the increased immersion of the bows, fly up to the wind, while the effect of the immersion of the after part will be to make her fall off.

The ill effects which have been described as attendant on the mal-position of the centre of effort of the sails, with respect to the height of sail; though they cannot be removed while the cause exists, and which may consist in the improper proportions of the masts and yards; may in some cases be diminished, by an alteration in the disposition of the weights on board the ship. If instead of supposing the ship to incline, from the action of the force of the wind at the point E, we suppose the effect of this force to produce the inclination, to be counteracted by the removal of a weight b, from a point N, at the fore part

of the ship, to another point O at the after part, then the ship will be maintained in a state of equilibrium by the action of the two equal forces a . E F and b . N O, and it will, therefore, move without longitudinal inclination, as long as the force of the wind remains constant; but any alteration in that force, must be met by a corresponding alteration in the position of the weight: also, when from the action of the water on the hull, the ship acquires an angular velocity, the angular momentum will be increased by that of these two forces; which may both be considered as weights acting at their respective distances from the centre of gravity of the ship. It is therefore evident, that an error in the position of the centre of effort of the sails cannot be remedied by any alteration in the disposition of the weights in the ship, except in peculiar cases of smooth water: and, further, if the error is, that the centre of effort is above the height of sail, the ship will labour under the disadvantage of a diminished area of sail, since the moment of sail must be in constant proportion to the moment of stability: and, if the centre of effort is too low, the ship may not be able to obtain all the advantage of motive power of which her stability would admit.

It appears, therefore, that unless the centre of effort of the sail is placed at the height of sail, a ship, however good her form, and the properties connected with it, may be, and whatever may be the care bestowed to render those properties most efficient, will labour under very serious disadvantages; while, on the contrary, a correct adjustment of this element, and a knowledge of the principles on which that adjustment depends, will place it in the power of a commander, to draw a maximum of advantage from the powers and properties of his vessel, since it will enable him to acquire the greatest possible efficient action from the motive power at his disposal.

As was before said, the determination of the height of sail must be classed among those problems of naval architecture, which, labouring under the difficulties attendant on the imperfect knowledge of fluids, cannot be attained by theory alone. It will now be shown that, by the aid of theory, sufficient deductions may be made from experiment to remedy its practical insufficiency. Throughout this article the sails have been reasoned on, as if they were plane surfaces, if this were the case

their centre of effort would coincide with their common centre of gravity; but from the flexibility of the materials of which they are made, the sails become, when acted upon by the force of the wind, curved surfaces; however, from the whole surface of sail with respect to height, being composed of several such surfaces, the error arising in practice from assuming the height of the common centre of gravity of the whole surface, to be the height of the centre of effort, will be very inconsiderable. Therefore, in practice the centre of effort of the sails, may be represented with respect to height, by their common centre of gravity.

Since we know, from the principles which have been explained, that when the centre of effort of the sails is at the true height of sail, the trim of the ship will not be subjected to alteration by any increase or diminution in the force of the wind: the height of sail for any trim may be determined by experiment, by first bringing the ship to that trim when she is at rest, and then adjusting the sails so that her water line when in motion may be parallel to this trim. This being admitted; it is evident, that by proceeding on the principles explained in this paper, and in Art. 16, Vol. 2, the maximum of advantage arising from the correct position of the centre of effort of the sail may be ensured, by first ascertaining, from experiment and observation, made with reference to the longitudinal position of the centre of effort, with respect to the centre of gravity of the ship, the most advantageous draught of water; and then determining the correct height of sail with respect to that draught of water.

The observations necessary to effect these objects, will of course require considerable patience and attention, but it must be considered, that they will not only enable a commander to derive the greatest possible advantage from the means at his disposal, but that they will afford correct data for perfecting those means. The following observations may suffice to explain the principle which should be pursued. The draught of water previous to sailing should be observed; and an instrument which will correctly measure the angle of inclination, should be fixed, with reference to this water line, that by means of it every deviation from this trim may be exactly known. This is rendered absolutely necessary, because, when a ship is in motion,

her correct trim, that is her horizontal water line, cannot be observed, in consequence of the accumulation and depression of the water which is caused by the motion. In fact, any alteration made in the trim of the ship, or the sails, founded on observations made with reference to the apparent water line, might be extremely hazardous, and certainly would not have the results expected, as this water line depends wholly on the circumstances which are in immediate operation. Having the instrument fixed, when the ship has acquired uniform velocity, observe the alteration which has taken place in her trim; as, until the velocity is uniform, the trim will be influenced by the force which accelerates the velocity, then if her longitudinal oscillations appear to be only influenced by the state of the sea, the centre of effort is correctly placed at the height of sail. Therefore, the height of the centre of gravity of the surface of sail set, will give the height of sail. But if at every change in the force of the wind, the vessel experiences a longitudinal oscillation; observe by the instrument its nature and degree, and make such a change in the adjustment of the sails as the foregoing principles have shown to be necessary, and when the tendency to longitudinal oscillation ceases, find the height of sail by calculating the height of the centre of gravity of the surface of sail. In this manner the correct height of sail for any trim may be found; while by observing at the same time, the comparative qualities of the ship when at each of these trims, (after the height of sail is determined for it,) that trim of the ship and sails may be determined, from which a maximum of advantage may be derived of the inherent good qualities of the ship, as far as the perfection of the materiel will admit, that is, as far as the position and proportion of the masts, yards, and sails, are adapted to the elements of the construction of the ship's body: while from knowing the best trim of the ship, and the true position of the centre of effort under the several circumstances of wind and sea, the naval architect will be in possession of sufficient data to make such alterations in the materiel as shall then ensure a maximum of advantage, with a maximum of the means. In fact, correct observations of this nature would go very far to remove much of the difficulty which theory, in

its application to some points in the practice of naval architecture at present labours under.

Since, from the fact, that when the impulse of the wind acts at the height of sail, a ship has no angular motion round its centre of gravity, the height of sail may, as has been shown, be easily determined by experiment, for any given water line; it will be possible to render this property available to the purpose of measuring the resistances experienced by bodies of various forms moving in a fluid; and also, by means of a simple geometrical construction, of ascertaining what proportion of the resistances acts positively, and what negatively; and also the quantity of the positive and negative vertical resistances acting on the body: and this will be attended with the advantage, that the method of applying the moving force in the experiment may be similar to its actual application in practice. This moving force may be obtained by having a vertical plane surface, fitted to move up and down a vertical mast, fixed in the body, with which the experiment is to be made. The direct force of the wind on this board, with different velocities, may be determined experimentally; or, the force of the wind, with any velocity a being known, its force, with any velocity $v \pm a$ may be estimated. The resistance, occasioned by the air on the fore side of the board, will render a correction necessary. Weights may also be used as a motive power; to this some difficulties would arise in practice, but none which could not be overcome by single mechanical expedients. However, it is only intended to show the application of the properties of the height of sail, to this purpose.

Let A D C B, Fig. 45, be a vessel, the extremities of which, A D and B C, are plane surfaces, inclined to the horizon at any given angles. Let G H be the mast, supposed to be at right angles to the surface of the water, that is, to the horizon. Let H be the correct height of sail; and let E F be a horizontal line, intersecting the planes A D and B C in T and S.

Then, since the angles of inclination of the planes A D and B C, to the horizontal line E F, are known, and as the proportion of the direct to the vertical resistance, on either plane, is as the sine to the cosine of the angle of inclination, the direc-

tions of the resultants of these resistances are respectively given in position, and will each be inclined to the horizon at an angle equal to that of the inclination of the plane to which they belong.

When the ship has acquired an uniform velocity in the direction A B, the direction of the wind coinciding with A B, suppose the centre of effort of the sail to be situated at the correct height of sail, H; then from H draw H F and H E, meeting the horizontal line E F in E and F, and making, with G H, the angles G H F and G H E, respectively equal to the complements of the angles of the inclination of the planes B C and A D; then H F E and H E F will respectively equal the angles of inclination of the planes B C and A D; and therefore F H and H E will represent the directions of the resultants of the resistances on them.

Now, from F H, or the greater, cut off F M equal to E H the less; and from M draw M P perpendicular to E F. Then in the triangle F P M, F P : P M :: cos. M F P : sin. M F P, and the angle M F P is equal to the angle B S F; therefore F P is to PM in the proportion of the direct resistance against the plane B C, to the vertical resistance against the same plane. Again,

$$O E : H O :: \cos. H E O : \sin. H E O$$
$$:: \cos. A T E : \sin. A T E;$$

that is, O E is to H O, as the direct resistance on the plane A D is to the vertical resistance on the same plane. And since F M is equal to E H, F P is to O E as the direct resistance on B C is to the direct resistance on A D; and P M is to H O as the vertical resistance on B C is to the vertical resistance on AD.

From H draw H K horizontal, and take K H to represent, in quantity and direction, the whole force of the wind to propel the ship; then divide K H in L, so that H L is to L K as F P is to O E; then K L and L H will represent, respectively, that part of the force of the wind which is destroyed by the direct resistances on A D and B C, and L K and H L will represent those resistances.

From L draw L N perpendicular to H K, to meet F H produced in N; then, in the similar triangles, H L N and F P M,

$$H L : L N :: F P : P M,$$

that is, H L is to L N as the direct resistance on B C is to the

vertical resistance; but H L is equal to the direct resistance; therefore L N will be equal to the vertical resistance. Now, from N draw N Q parallel to H K, and make N Q equal to L K, join Q K; then, because N Q is equal and parallel to L K, Q K must be parallel to L N. Produce Q K to R, and make Q R to L N as H O to P M; that is, as the vertical resistance on A D is to the vertical resistance on B C; and since L N equals the vertical resistance on B C, Q R will be equal to the vertical resistance on A D. Join R H; then H R will be the resultant of the resistance of the water on the planes B C and A D. Now, if the surface of one extremity of the vessel, as A D, be altered to any form A V D, and, with the same velocity, the height of sail is found to be at *h*, from *h* draw *h k* horizontal, and take *k h* to K H as the force of the wind observed after the alteration to that observed before the alteration: then *hk* will be equal to the horizontal resistance of the water. Now, since the extremity B C of the vessel remains the same, and the velocity is supposed constant, the resistances on B C will remain unaltered; therefore on *h k* take *h l* equal to H L, and from *l* draw *l n* perpendicular to *h k* and equal to L N.

Also, since *h k* is equal to the whole horizontal effort of the water, and *h l* is equal to that which acts on the surface B C, *l k* will be equal to the direct negative resistance experienced by the surface AVD.

Now, from O, on the horizontal line O E, set off a distance O*e* such that O *e* : O E :: *l k* : L K then from *e*, with a radius equal to F M or H E, describe a circle cutting O H in *h′*; then O *e* and *h′* O will represent, respectively, the direct and vertical resistances on the surface AVD, in the same proportion as O E and H O represent the direct and vertical resistances on the surface A D.

Therefore, from *n* draw *n q* parallel to *h k*, and make *n q* equal to *l k*; join *q k*, it will be parallel to *l n*, and, therefore, vertical. Produce *q k* to *r*, and make *q r* to Q R as *h′* O is to H O, and *q r* will be the negative vertical resistance on AVD.

In the same manner, if any other surface be substituted instead of AVD, the direct and vertical resistances experienced by it may be found: and, on the same principle, the resistances on any stern AVD, being ascertained by the above method, alterations may be made in the form of the bows, and the resist-

ances experienced after the alteration may be determined, provided the velocity of the ship remains constant.

Since the resistances cannot be compared unless the velocities are the same, an apparent difficulty arises from the uncertain nature of the motive power, if the impulse of the wind be used; but this may be avoided, by setting off the observed velocities for each body, when acted upon by any various forces of the wind, as the abscissæ of a curve, the ordinates of which will be the corresponding resistances determined by the method which has been explained: through the extremities of these ordinates a curve may be passed. In this manner the direct and vertical resistances observed, for each bow or stern experimented on, may be formed into curves, by means of which comparisons may be made of the various resistances experienced by the several bodies.

Art. XXX.—*Account of the Trial of the Paddle-wheels fitted on board His Majesty's Ship Galatea. By* Captain Napier, R.N., C.B.

(*To the Editors of Papers on Naval Architecture.*)

Gentlemen,

The following description of the paddle-wheels, fitted under my direction on board H. M. Ship Galatea, with the trials which have been made with them, are offered for insertion in your work.

I remain, &c.
Charles Napier.

H. M. Ship Galatea,
Spithead, 10*th June,* 1829.

The object which is intended to be obtained by the following method of fitting a ship with paddle-wheels is to render the strength of a ship's crew available in moving a ship in a calm.

The same paddle-wheel arms, including the first lengths of cast-iron shaft on which they are hung, have been fitted in the Galatea, that were taken out of the Active; the rest of the machinery is new, to suit the difference between applying the power of the men by winches as in the present instance, and

by a capstan motion as in the former instance in the Active. Each paddle-wheel consists of a cast-iron nave, with eight wrought-iron arms fitted into it, to which are bolted the paddle-boards, forming a paddle-wheel of 13 ft. 5 in. extreme diameter. Two sets of paddle-boards were provided, the one 7 ft. long by 2 ft. deep, and the other 6 ft. long by 2 ft. deep; they admit of being shifted in or out from the centre upon the iron arms of the wheels. Rope stays, crossing each other and tightened by lanyards, extend from paddle-board to paddle-board, to unite the strength of all the arms. The paddle-wheels can be readily unshipped from the shaft, and the arms from the nave. The nave and arms stand out dishing, the nave being a few inches from the ship's sides. The first length of shaft extends in board close under the main deck, a little before the main hatchway, and is connected by a sliding coupling box with a second length of shaft which reaches to midships under the ladder way. The machinery is very simple: a cast-iron spur-wheel, 3 ft. 8 in. diameter, hung upon the end of the shaft, extends up the ladder-way, and is worked by another spur-wheel, 3 ft. in diameter, hung upon another cast-iron shaft, extending horizontally above the main deck, a sufficient distance towards the ship's sides for the application of a range of winches, fore and aft, just clear of the guns and of the hatchways, &c. A cast iron bevelled wheel of 3 ft. diameter, on the end of this shaft, is worked by two bevelled pinions of 1 ft. 10 in. diameter, fixed respectively, one on the end of the forward, the other on the end of the after, range of winches. The winches, which are 1 ft. 5 in. radius, are like the chain-pump winches, which, indeed, are used at the extremities; there are on each side of the ship six forward and seven aft, from 7 to 9 feet in length, which on both sides admit of the application of 230 men. By the proportions of the cogged wheels, about 2½ revolutions of the winches give one revolution to the paddle-wheels. A sliding coupling box is fitted in midships, for connecting or disconnecting the shafts of both sides, and two sliding coupling boxes are also fitted between the first and second lengths of shafts. By these means, the paddle-wheels can be worked connectedly or unconnectedly; both wheels together, forwards or backwards, or either one forwards and the other backwards, which

is very advantageous in putting about. Both paddle-wheels can also be worked by the winches on either side, while the winches on the other side are removed for fighting the guns. Lastly, either one or both paddle-wheels, by means of the outer coupling boxes, can be easily disengaged from the motion of the winches.

The whole of the machinery is so contrived, as when not wanted, to be readily unshipped and stowed away.

The first trial was made on the 15th May, when the Galatea, stored and provisioned for four months, with 85 tons of water, slipped her moorings off Common Hard half an hour before high water, the flood running nearly a knot against her. The whole crew consisted of 190 working men, two-thirds of whom manned the winches, when the paddle-wheels made eleven revolutions in a minute, her rate being two and a half knots. For a short time, when passing the platform, the winches were manned by the whole of the crew, when her rate by log was nearly three knots. When working with the two divisions of the crew, the third division spelled them every five minutes; the men were not at all fatigued by their exertions. The paddle-boards used in this trial were the longer set, of seven feet in length. The lowest paddle during the revolution was just below the surface of the water. When we hauled round the buoy of the spit, the wind freshening, the paddle-wheels were disconnected, and we made sail. The efficiency of the paddle-wheels was fully proved by this trial.

The second trial of the Galatea was made at Spithead, to compare her speed, when propelled by the men at the winches, with the speed of the Briton, when towed by boats. The Galatea had then received her powder on board, and had completed her water to 109 tons. The Briton was towed by her own boats, those of the Pallas, and two barges of the Galatea, in all 10 boats, with 125 men. The Briton was towed at the rate of 2 knots 2 fath., and the Galatea, with two-thirds of her working men, who in this trial were 193, her paddle-wheels making ten revolutions in a minute, beat her considerably; and when the winches were manned by the whole of the men, the revolutions were increased to 13, and her speed to 3 knots, or 3 knots 2 fath., and she then went round the Briton in fine

style, in returning to her anchorage. Though the Briton set her jibs, staysails, and spanker, she was still left behind. In this trial, the Galatea had the 7 ft. paddles on one side, and the 6 ft. paddles on the other, with the shafts unconnected, the upper edges of the lowest paddles being immersed a few inches below the water's surface: the wheel of the 6 ft. paddles made half a revolution in a minute more than the wheel with the 7 ft. paddles, and perhaps had a trifling advantage observable at the helm. The speed of both ships was taken from the Briton.

From the result of these trials, I consider that one watch will propel the Galatea two knots; two-thirds of the ship's company $2\frac{1}{2}$; and the whole crew, with six weeks provisions, so that the paddle-wheels could work with their full diameter, from 3 knots to 3 knots 2 fath.; and with the war establishment, at the rate of 4 knots. Even with the peace establishment, when stimulated with the desire of obtaining any particular object, I have no doubt that the crew could work regularly at the winches the greater part of the day; and with the war establishment, that they could continue working for any required length of time.

Art. XXXI.—*Method of Communicating Orders from a Ship's Deck to the Tops, by means of Speaking Pipes. By* Mr. W. Parsons.

(*To the Editors of the Papers on Naval Architecture.*)

Gentlemen,

From frequent conversations with officers of the Royal Navy, I understand that great difficulty is always experienced in blowing weather, in communicating orders from the deck of a ship to the men in the tops; in such weather it is necessary that the men should be particularly attentive to the orders given, and prompt in executing them, but at this very time it is impossible for them to hear what the orders are, thus causing great confusion and frequently considerable dan-

ger. It is not improbable that many vessels may have been lost from this cause.

To obviate these difficulties, I suggested to Capt. Charles Napier, the propriety of fitting a speaking pipe from the deck up the sides of the masts into the tops, which he very kindly gave me permission to try in the Galatea. This pipe is about one inch in diameter, made in lengths of twelve feet, of the thinnest sheet copper, the seams soldered together, and the ends made to fit about two inches into each other, and left loose to work with the play of the mast; two straps of copper were soldered to each length, to fasten it to the mast; it was placed in the angle formed by the mast and side fish, which covers the heads of the screws in the iron hoops; it is thus protected from injury, and would not be perceived by a casual observer. It runs straight up to the trestle-tree, where it forms a right angle, the horizontal arm being carried close under the trestle-tree to its after end, where it forms another right angle, and is taken straight up through the top rim, on which it is turned all round; a shifting mouth-piece about three feet long is made to fit into it. The lower end is bent round the mast, and brought right abaft it at about five feet above the deck; three shifting mouth-pieces, each three feet long, were fitted into the lower end, for the use of the officers. This pipe was fitted to the main mast, and on trial was found to answer perfectly well.

I am about to make trial of the patent India rubber hoses for this purpose, and have no doubt of their answering; these hoses can be coiled up and stowed below in moderate weather, and when in use may be hung loose from the top rail to the deck; the cost will be about the same as copper.

It may sometimes be desirable to give orders to the men in the tops so as not to be heard by a vessel near at head, which can be readily done through these speaking pipes.

I am, gentlemen, your humble servant,

W. Parsons.

Portsmouth, 12*th June*, 1829.

ART. XXXII.—*Remarks on the Application of the Physical Strength of the Crew of a Ship, as a motive Force to propel her.* *By* JOHN FINCHAM, ESQ.

IN all attempts to apply the physical strength of the crew of a ship, as a motive power, to communicate velocity to the vessel, the principal endeavour should be to effect this object by those means which will require the least possible exertion on the part of the men; since one of the advantages proposed to be gained is the bringing an enemy's ship to action; and if, by the exertions necessary to effect this, the men are so fatigued as to engage the enemy at a disadvantage, the result may be disastrous.

It is well known that men's physical strength is not only increased by habitual exertion, but that it takes its direction from the nature of that exertion; therefore, when it is desired to produce results from the power of any particular class of men, advantage may be taken of this fact. Now, though seamen are not unused to the application of strength required for the winch or the capstan, by far the most customary labour to them is that of pulling horizontally at a rope; and it may, therefore, be inferred that they are capable of making equal, or even greater, muscular exertion at this than at any other species of manual labour. And that this must be the most advantageous means by which the force of the crew can be applied to propel a ship.

The author of this paper is further confirmed in this conclusion by the results of some experiments made by him to ascertain the comparative degree of exertion necessary to produce a given effect, with various methods of applying the strength of a man. The proportions between the labour at a winch and at a rope, pulled horizontally, was as 15 to 11; and, since the men employed in the experiment were not more habituated to the one application of their labour than to the other, this difference, though great, must be a true measure of

the disadvantage attendant on the use of the winch in comparison to that of a rope, pulled horizontally.

All attempts to increase this motive power, by means of machinery, in its transmission to the paddles, must be injurious, as an increase of power can only be attained by a sacrifice of time, and, consequently, of velocity; while the effect of a part of motive power will actually be lost, from its being employed to overcome the friction of the machinery. Therefore the best method of applying the force of men pulling horizontally at a rope, to the paddles, will be that which is the most simple, which quality necessarily involves the further advantage of the several parts being more easily repaired or replaced in the event of accident.

The following method is proposed as combining these advantages. A rigger, or barrel, should be attached to the inner end of the paddle-shaft, to receive two or three turns of an endless rope, the disengaged part of which should be led round the deck by means of leading blocks, and be of sufficient length to admit of the number of men being applied to it whose strength, exerted by pulling horizontally on this rope, may be requisite to communicate motion to the vessel.

Fig. 46 represents an athwartship section of the ship, with the rigger attached to the inner end of the paddle-shaft.

Fig. 47 shows the method in which it is proposed that the rigger shall work in the main hatchway; and Fig. 48 shows the plan of the paddle, paddle-shaft, and rigger; with the method of leading the endless rope over the rigger, and round the deck.

The inner end of the shaft to each paddle-wheel may extend as far as the centre of the ship, that the paddles may, if necessary, be worked in connexion, as well as separately. By having the rigger to work in the main hatchway, as shown in the drawing, the advantage is gained of having the rope to work either on the deck above or on that below the paddle-shaft, as may be found most convenient.

The diameter of the rigger must be proportioned to that of the paddle-wheels, that a sufficient velocity may be communicated to them, according to the power applied, with the men walking at the pace most usual to them, when in the act of pulling at a rope. In order that the endless rope may have suffi-

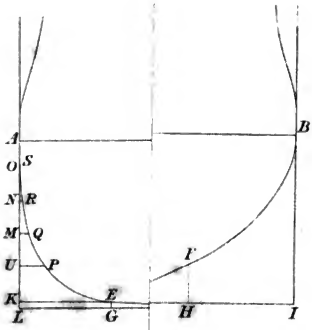


Fig. 10.

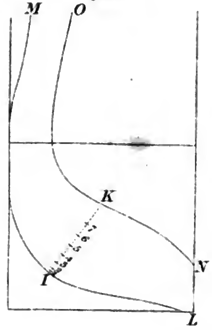
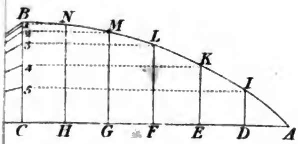


Fig. 7.



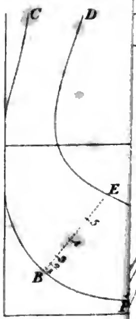
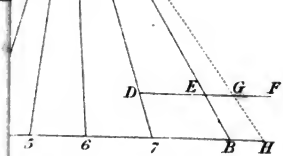


Fig. 9



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Pl. 2.

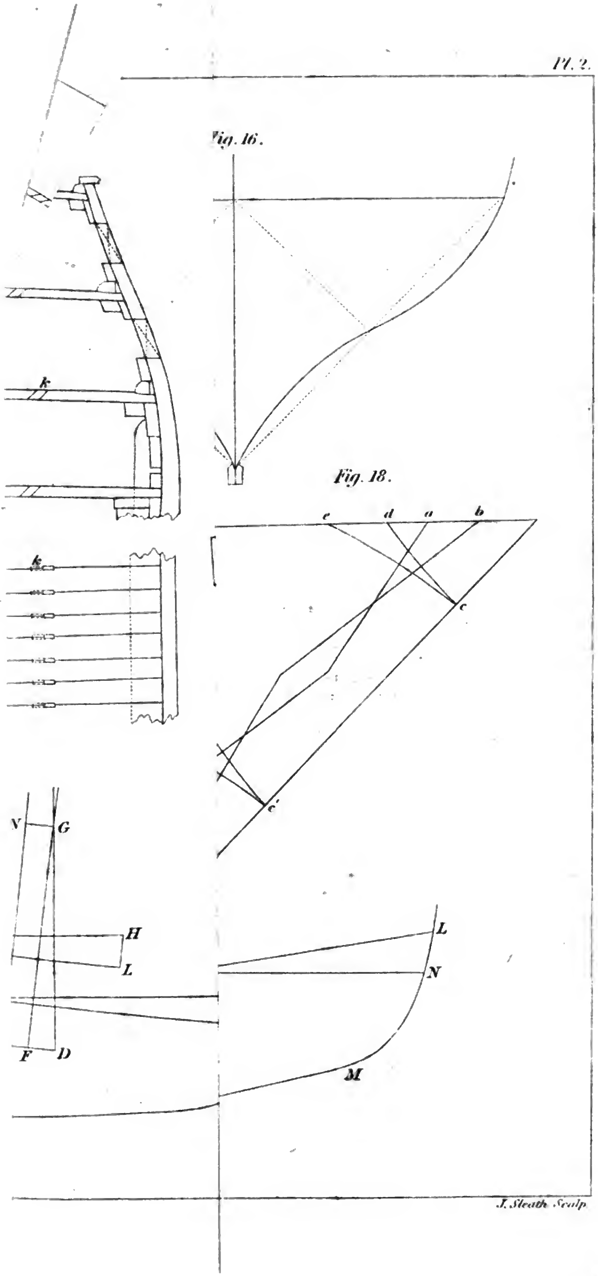

Fig. 23.

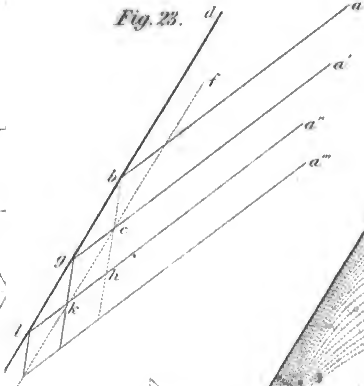

Fig. 24.

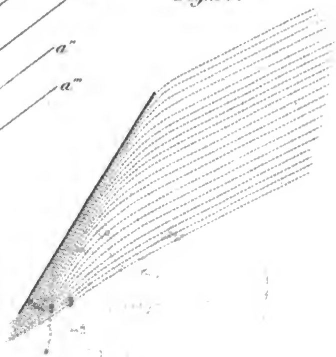

Fig 29.

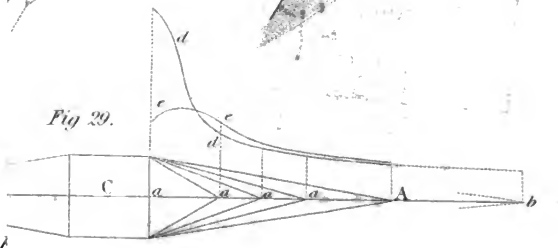

Fig. 30.

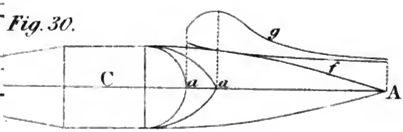

Fig. 31.

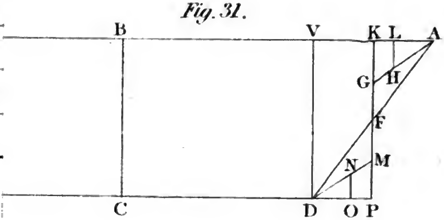

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Fig. 38.

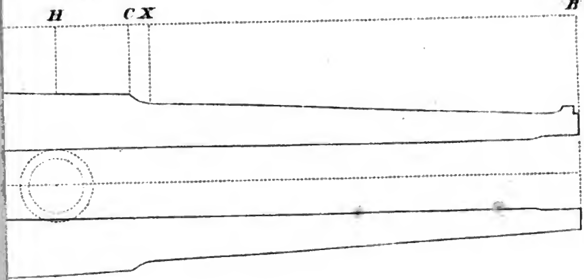


Fig. 39.

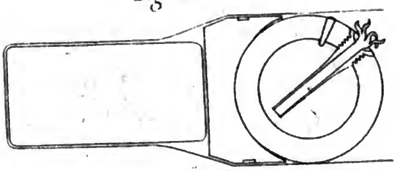
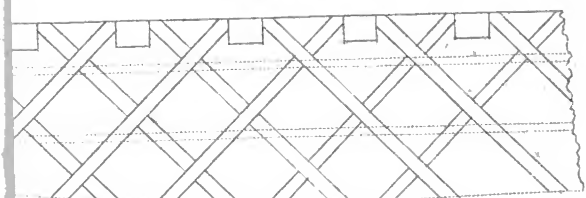


Fig. 37.



J. Sleath

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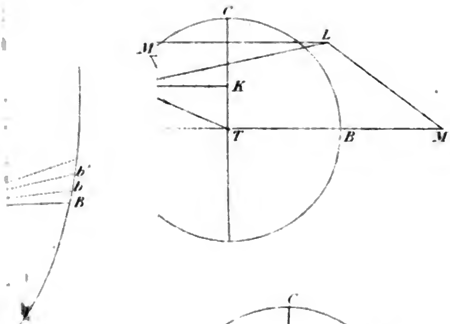
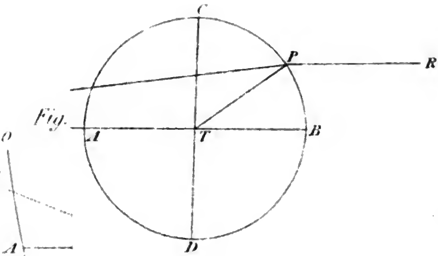


Fig.



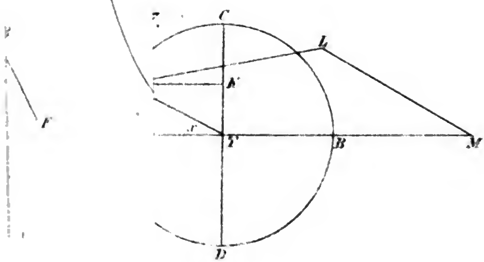
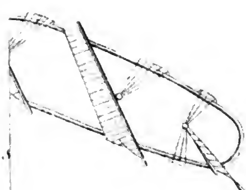


Fig. 101.



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